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ELECTROMAGNETIC SHADOWING OVER A WIDE RANGE OF FREQUENCIES,(U)

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ELECTROMAGNETIC SHADOWING OVER A WIDE RANGE OF FREQUENCIES

by

I. I. Grodnev

FOREIGN TECHNOLOGY DIVISION

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PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
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Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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ELECTROMAGNETIC SHADOWING OVER A WIDE RANGE OF FREQUENCIES.

I. I. Grodnev.

Page 2.

In the manuscript is presented the theory of electromagnetic shadowing over a wide range of frequencies from zero to SHF band. Is given single procedure and the engineering formulas of the calculation of screens both for electrical and for magnetic fields in the different mode/conditions of the use of screens (statics, electrodynamics, the wave mode/conditions). Are examined the special feature/peculiarities of the shadowing of coaxial and symmetrical cable circuits taking into account protection from mutual and outside interferences. Are investigated fundamental laws and the characteristics of the multilayer combined screens and are recommended the optimum constructions of screens. Are given to recommendation regarding the shadowing of continuous, tape/strip and braiding screens in the technology of the communication cables and radio-frequency cables.

The book is intended for engineering-technical workers, who are occupied by the questions of the protection of communications from interferences, and also it can be used

by the students of the old courses of institutes as textbook.

Page 3. No Typing.

Page 4.

PREFACE.

The contemporary development of electrical communication and radio electronics is characterized by the expansion of the range of the utilized frequencies and by the mastery/adoption of decimeter, centimeter and millimetric ranges. This causes the need for the protection of equipment and circuits of the transmission from the effect of electromagnetic interferences in wide frequency range. Radical means of defense are the screens with the aid of which is localized electromagnetic field, created by the source of interferences. The methods of the calculation of screens, illuminated in the literature, are based on quasi-stationary mode/conditions and therefore are valid only for the limited frequency band - to 10^8 Hz. As a rule, is examined the action of screen only relative to magnetic wave, and single procedure and the formulas of the calculation of screens are absent.

In this book are presented the bases of the theory of electromagnetic shadowing over a wide range of frequencies - from zero to SHF band. Is given single procedure and the

engineering formulas of the calculation of screens both for electrical and for magnetic fields in the different mode/conditions of the use of screens (statics, electrodynamics, the wave mode/conditions). Are investigated fundamental laws and the characteristics of single-layer and multilayer screens and are recommended their optimum constructions. Are examined the continuous, tape/strip and braiding screens, used in the technology of the communication cables and radio-frequency cables. The book is intended for specialists, who are occupied by the questions of the protection of communications and radio mechanics from interferences, and, furthermore, it can be useful for the students of old courses as textbook.

Observations about the book request to guide to: Moscow-center, Chistoprudnyy bul'var, 2. Publishing house "Svyaz'".

Author

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Chapter 1.

BASIC POSITIONS OF THE THEORY OF ELECTROMAGNETIC SHADOWING.

1.1. Formulation of the problem.

Communication cables and radio-frequency cables are shielded from outside interferences and the effect of the electric power line, overhead electric transport power lines of electric RR, man-made interferences, radio stations and so forth with the aid of electromagnetic screens. Especially sharply came up the question concerning interference elimination in connection with the expansion of the band of the utilized frequencies and the wide mastery/adoption of the range of decimeter and microwaves. The existing methods of the calculation of screens, which are based on quasi-stationary mode/conditions (without taking into account of bias currents) and the use of a transverse electromagnetic wave TEM are suitable only for the limited

frequency band - approximately to 10^8 Hz. At the more high frequencies when wavelength less or is commensurable with the diameter of screen $(\lambda \leqslant D_0)$, one should use the complete equations of electrodynamics, taking into account in this case the bias currents and higher-order wave of two types: transverse-magnetic TM (wave E, Fig. 1.1a), that characterize the shadowing of magnetic field, and transverse electric TE (wave H, Fig. 1.1b), characterizing the shadowing of electric fields.

The existing theory of shadowing is limited to the examination of the action only of magnetic screens, and the investigation and the mathematical vehicle, which concern the calculations of electrical shields, in it are absent. In the literature also is not given the single procedure of calculation of screens, but are given only formulas for the different mode/conditions of the use of screens (static, electrodynamic, wave).

However, under the actual conditions of shadowing, it is necessary to consider the effect both of magnetic and electric fields. Moreover depending on conditions can predominate one or the other component of field.

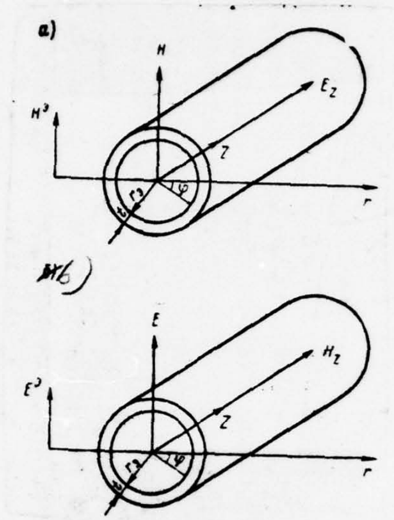

Fig. 1.1. Transverse magnetic TM (a) and transverse electrical TE (b) waves.

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Usually at a distance from the source of the order of wavelength λ, field has the expressed electrical or magnetic character. For frequency 10^9 Hz, this distance is equal to 0.3 m (wavelength), while for frequency 10^6 Hz — 300 m. At a distance, approximately larger (5-6) λ from radiation source, field accepts flat/plane layout and is propagated in

the form of the plane wave whose energy is divided equally between electrical and magnetic components. Powerful magnetic fields, as a rule, are created by circuits with low wave impedance, high current and a small jump/drop in the voltages, but intense electric fields - by circuits with high resistor/resistance, high voltage and low current.

For a plane wave in free space, wave impedance is equal to $Z_{A}^{EH}=Z_0=\sqrt{\mu/\varepsilon}=376{,}7$ ohm. For a field with the predominant electrical component, wave impedance is substantially more than $(Z_{A}^{E}>Z_0)$, while for a magnetic field is substantially lower $(Z_{A}^{H}<Z_0)$ value of wave impedance for a plane wave.

The target/purpose of this work are the study of the processes of the shadowing of electromagnetic fields at superhigh frequencies and the recommendation of the single standardized engineering calculations of screens for electrical and magnetic fields in the different mode/conditions of use. All conclusions are given for cylindrical screens in connection with the constructions of radio-frequency cables and communication cables and are based on the solution to the fundamental equations of electrodynamics - the equations of Maxwell. For a wave

mode/conditions these equations take the form

$$\left.\begin{aligned}\mathrm{rot}\,\dot{H} &= \sigma\dot{E} + i\,\omega\varepsilon\,\dot{E}\\ \mathrm{rot}\,\dot{E} &= -i\,\omega\mu\,\dot{H}\end{aligned}\right\}. \quad (1.1)$$

equation (1.1) it is possible to express differentially as follows:

for a TM wave taking into account the action of longitudinal electric field $\dot{E}_z$

$$\frac{\partial^2 \dot{E}_z}{\partial r^2} + \frac{1}{r}\frac{\partial \dot{E}_z}{\partial r} + \frac{1}{r^2}\frac{\partial^2 \dot{E}_z}{\partial \varphi^2} = (i\,\omega\mu\sigma - \omega^2\mu\varepsilon)\,\dot{E}_z; \quad (1.2)$$

for a TE wave taking into account the action of longitudinal magnetic field $\dot{H}_z$.

$$\frac{\partial^2 \dot{H}_z}{\partial r^2} + \frac{1}{r}\frac{\partial \dot{H}_z}{\partial r} + \frac{1}{r^2}\frac{\partial^2 \dot{H}_z}{\partial \varphi^2} = (i\,\omega\mu\sigma - \omega^2\mu\varepsilon)\dot{H}_z. \quad (1.3)$$

In this case, field changes along z axis were not considered. The first member $(i\omega\,\mu\sigma = \kappa_{м}^2)$ right side is caused by conduction currents and characterizes processes in metal, but the second term $(\omega^2\,\mu\varepsilon = \kappa_{д}^2)$ is caused by bias currents and characterizes processes in dielectric.

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For determining the screening effect of cylinirical

screen, let us examine the flow of energy which is propagated in radial direction from perturbation source to screen and for screen. The energy current density in this direction is expressed according to the law of Poynting through components electrical E and magnetic H of fields. For the transverse magnetic wave TM (magnetic shielding) Poynting's vector takes the form $\Pi = \mathrm{Re}\,\frac{1}{2}\left[E_z H_\varphi\right]$. The wave impedance, exerted to this flow by metallic or dielectric medium, is expressed as the components of the electrical and magnetic fields:

$$Z_r = \frac{E_z}{H_\varphi}. \quad (1.4)$$

For a transverse electrical wave TE (electric screening) the vector of Poynting and wave impedance will be respectively

$$\left.\begin{aligned} \Pi &= \mathrm{Re}\,\frac{1}{2}\left[E_\varphi H_z\right] \\ Z_r &= \frac{E_\varphi}{H_z} \end{aligned}\right\}. \quad (1.5)$$

Field component E_z and H_z we find by solving of the differential second order equations given above. Components H_φ

and E_φ. for a metal and a dielectric we find from the relationship/ratios:

for metal

$$\left.\begin{aligned} H_\varphi &= \frac{1}{i\omega\mu}\,\frac{\partial E_z}{\partial r} \\ E_\varphi &= -\frac{1}{\sigma}\,\frac{\partial H_z}{\partial r} \end{aligned}\right\};\ (1.6)$$

for the dielectric

$$\left.\begin{aligned} H_\varphi &= \frac{1}{i\omega\mu}\cdot\frac{\partial E_z}{\partial r} \\ E_\varphi &= -\frac{1}{i\omega\varepsilon}\cdot\frac{\partial H_z}{\partial r} \end{aligned}\right\}.\ (1.7)$$

Integration constant we find with the aid of the equality tangential component electrical and magnetic fields (Fig. 1.2) on boundaries dielectric - screen (within screen $r=r_э$) and screen - dielectric (outside screen $r=r_э+t$):

$$\left.\begin{aligned} E^п_д \pm E^о_д &= E_м \\ H^п_д \pm H^о_д &= H_м \end{aligned}\right\} \text{with } r=r_э; \qquad (1.8)$$

$$\left.\begin{aligned} E_x S = E_m \\ H_x S = H_m \end{aligned}\right\} \text{ with } r = r_0 + t, \qquad (1.9)$$

where E^n, H^n. are components of the incident wave, and E^o, H^o are components of the wave reflected; S - screening constant; r_0. is a radius of screen; t is thickness of screen. The index of "d" is related to dielectric, while index "m" - to metal.

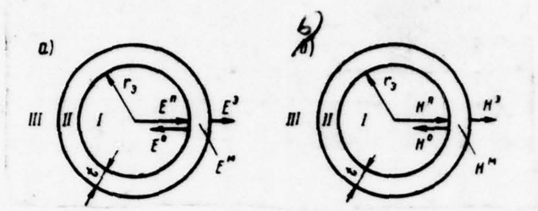

Fig. 1.2. To the determination of integration constant for the electrical (a) and magnetic (b) fields: $E^п, H^п$ – the incident field; E^o, H^o - the field reflected; $E^м, H^м$ - field in metal; $E^э, H^э$ – a field after screen.

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1.2. Shadowing of magnetic field.

In this case it is to operate with the transverse magnetic wave TM. Perturbation source is a longitudinal-operating electrical wave E_z which it creates transverse magnetic field H_φ, being subject to shadowing (Fig. 1.1a). For the determination of the shielding

characteristics first of all, it is necessary to determine the components the electrical E_z and magnetic H_φ of fields. The value of the wave impedance, exerted to the radially directed energy flow, will be determined through these components: $Z_r = E_z / \dot{H}_\varphi$. The equation of Maxwell in cylindrical coordinate system relatively E_z for a metal and dielectric takes the form

$$\frac{\partial^2 E_z}{\partial r^2} + \frac{1}{r}\frac{\partial E_z}{\partial r} + \frac{1}{r^2}\frac{\partial^2 E_z}{\partial r^2} = \begin{cases} \kappa_м^2 E_z - \text{для металла,} \ (1) \\ -\kappa_д^2 E_z - \text{для диэлектрика,} \ (2) \end{cases} \quad (1.10)$$

Key: (1) for a metal,

(2) for the dielectric,

where $\kappa_м = \sqrt{i\omega\mu\sigma}$ is a propagation factor in metal; $\kappa_д = \omega\sqrt{\mu\varepsilon}$ - propagation factor in dielectric.

The solution to this equation for a dielectric takes the form

$$E_z = \sum_{n=0}^{\infty} [A_n J_n(\kappa_д r) + B_n H_n(\kappa_д r)] \cos n\varphi, \quad (1.11)$$

where J_n and H_n are cylindrical functions of the first (Bessel) and third (Hankel) kind; A_n and B_n are integration constant; r and ϕ - radial and tangential coordinates.

On the basis of equ. (1.6), we determine the second component:

$$H_\varphi = \frac{1}{i\omega\mu}\cdot\frac{\partial E_z}{\partial r} = \frac{\kappa_\text{д}}{i\omega\mu}\sum_{n=0}^{\infty}[A_n J'_n(\kappa_\text{д} r) - B_n H_n(\kappa_\text{д} r)]\cos n\varphi. \quad (1.12)$$

In these expressions the first members, who increase with increase in r, characterize the waves E_z^o and H_φ^o, reflected a the second members decreasing with increase in r, the incident waves $E_z^\text{п}$ and $H_z^\text{п}$:

$$\left.\begin{aligned} E_z^\text{п} &= \sum_{n=0}^{\infty} B_n H_n(\kappa_\text{д} r)\cos n\varphi \\ H_\varphi^\text{п} &= -\frac{\kappa_\text{д}}{i\omega\mu}\sum_{n=0}^{\infty} B_n H'_n(\kappa_\text{д} r)\cos n\varphi \\ E_z^\text{o} &= \sum_{n=0}^{\infty} A_n J_n(\kappa_\text{д} r)\cos n\varphi \\ H_\varphi^\text{o} &= \frac{\kappa_\text{д}}{i\omega\mu}\sum_{n=0}^{\infty} A_n J'_n(\kappa_\text{д} r)\cos n\varphi \end{aligned}\right\} \text{ with } r < r_\text{э}, \quad (1.13)$$

where $Z_0 = \frac{i\omega\mu}{\kappa_\text{д}} = \frac{i\omega\mu}{i\omega\sqrt{\mu\varepsilon}} = \sqrt{\frac{\mu}{\varepsilon}} = 376{,}7$ ohm is wave dielectric resistance for a plane wave.

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Wave dielectric resistance for the incident and reflected waves of any component:

$$Z_{\text{Д}}^{\text{п}} = \frac{E_z^{\text{п}}}{H_\varphi^{\text{п}}} = -Z_0 \frac{H_n(\kappa_{\text{Д}} r)}{H_n'(\kappa_{\text{Д}} r)}, \quad (1.14)$$

$$Z_{\text{Д}}^{\text{о}} = \frac{E_z^{\text{о}}}{H_\varphi^{\text{о}}} = Z_0 \frac{J_n(\kappa_{\text{Д}} r)}{J_n'(\kappa_{\text{Д}} r)}. \quad (1.15)$$

With large arguments $(\kappa_{\text{Д}} r)$ wave dielectric resistance take the form: $Z_{\text{Д}}^{\text{п}} = -Z_0 = -\sqrt{\mu/\varepsilon}$, $Z_{\text{Д}}^{\text{о}} = Z_0 = \sqrt{\mu/\varepsilon}$. Different signs of $Z_{\text{Д}}^{\text{п}}$ and $Z_{\text{Д}}^{\text{о}}$ attest to the fact that falling and reflected the waves are directed to different sides.

Let us determine now component E_z and H_φ and respectively wave impedance $Z_{\text{м}}$ for a metal. The solution to the equations of Maxwell for conducting medium (1.10) with coefficient $\kappa_{\text{м}}$ takes the form

$$\left.\begin{aligned} E_z &= \sum_{n=0}^{\infty} [C_n I_n(\kappa_{\text{м}} r) + D_n K_n(\kappa_{\text{м}} r)] \cos n\varphi \\ H_\varphi &= \frac{1}{i\omega\mu}\frac{\partial E_z}{\partial r} = \frac{\kappa_{\text{м}}}{i\omega\mu}\sum_{n=0}^{\infty} [C_n I_n'(\kappa_{\text{м}} r) - D_n K_n'(\kappa_{\text{м}} r)] \cos n\varphi \end{aligned}\right\}, \quad (1.16)$$

where I_n and K_n are the modernized cylindrical functions of the first (Bessel) and second (Neumann) kind of composite argument; C_n and D_n are integration constant.

Respectively electrical and magnetic fields for the incident and reflected waves will be

$$\left.\begin{aligned}
E^{\text{п}} &= \sum_{n=0}^{\infty} D_n K_n(\kappa_{\text{м}} r)\cos n\varphi \\
H_{\varphi}^{\text{п}} &= -\frac{\kappa_{\text{м}}}{\mathrm{i}\,\omega\mu}\sum_{n=0}^{\infty} D_n K_n'(\kappa_{\text{м}} r)\cos n\varphi \\
E_z^{\text{о}} &= \sum_{n=0}^{\infty} C_n I_n(\kappa_{\text{м}} r)\cos n\varphi \\
H_{\varphi}^{\text{о}} &= \frac{\kappa_{\text{м}}}{\mathrm{i}\,\omega\mu}\sum_{n=0}^{\infty} C_n I_n'(\kappa_{\text{м}} r)\cos n\varphi
\end{aligned}\right\} \quad \text{with.} \quad r_0 \leqslant r \leqslant r_0 + t. \qquad (1.17)$$

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Here $Z_{\text{м}} = \frac{\mathrm{i}\,\omega\mu}{\kappa_{\text{м}}} = \frac{\mathrm{i}\,\omega\mu}{\sqrt{\mathrm{i}\,\omega\mu\sigma}} = \sqrt{\frac{\mathrm{i}\,\omega\mu}{\sigma}}$ is wave impedance of metal.

Values of the wave impedance of the conducting medium for any n of field component:

$$\left.\begin{aligned}
Z_{\text{м}}^{\text{п}} &= \frac{E_z^{\text{п}}}{H_{\varphi}^{\text{п}}} = -Z_{\text{м}}\frac{K_n(\kappa_{\text{м}} r)}{K_n'(\kappa_{\text{м}} r)} \\
Z_{\text{м}}^{\text{о}} &= \frac{E_z^{\text{о}}}{H_{\varphi}^{\text{о}}} = Z_{\text{м}}\frac{I_{\text{м}}(\kappa_{\text{м}} r)}{I_{\text{м}}'(\kappa_{\text{м}} r)}
\end{aligned}\right\}. \qquad (1.18)$$

In the range of high frequencies when $\kappa_{м}r \geqslant 5, \frac{I_n(\kappa_{м}r)}{I'_n(\kappa_{м}r)} \to 1$ and $\frac{K_n(\kappa_{м}r)}{K'_n(\kappa_{м}r)} \to 1$ we will obtain

$$\left.\begin{aligned} Z_{м}^{п} &= -Z_{м} = -\sqrt{\frac{i\omega\mu}{\sigma}} \\ Z_{м}^{о} &= Z_{м} = \sqrt{\frac{i\omega\mu}{\sigma}} \end{aligned}\right\}. \tag{1.19}$$

Here the wave impedance of the incident and reflected waves also has different signs, which indicates reversal of direction of the motion of these waves.

Let us examine electromagnetic fields, which operate inside and outside screen, and also in it is thicker than the screen (Fig. 1.2b). In region I within screen, operate the incident and reflected fields. For each n-component of field, it is possible to write: for an electric field - $E_z^{п}-E_z^{о}$, for a magnetic field - $H_{\varphi}^{п}+H_{\varphi}^{о}$.

The field reflected we express as the coefficient of reaction P_n:

$$\left.\begin{array}{l} E_z^n - E_z^n P_n = E_z^n(1-P_n) = E_z(1-P_n) \\ H_\varphi^n + H_\varphi^n P_n = H_\varphi^n(1+P_n) = H_\varphi(1+P_n) \end{array}\right\}, \qquad (1.20)$$

where E_z and H_φ - the components of the electrical and magnetic fields of perturbation source.

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In region III, outside screen electromagnetic field is expressed as the screening constant S_n, characterizing the ratio of field in any point of space in the presence of screen ($E^\bullet$ and $H_\varphi^\bullet$) ,to this same point without screen (E_z and H_φ):

$$\left.\begin{array}{l} E_z^\bullet = E_z S \\ H_\varphi^\bullet = H_\varphi S \end{array}\right\}. \qquad (1.21)$$

In region II in thicker than the screen will operate the fields

$$\left.\begin{array}{l} E_z = E_z^м \\ H_\varphi = H_\varphi^м \end{array}\right\}. \qquad (1.22)$$

For the solution to stated problem and, in the first place, the determinations of the integration constants and screening constants S_n and of the reaction of screen P_n we

will use the continuity condition of tangential components E_z and H_φ fields on the interface of mediums dielectric - screen $(r=r_э)$ and screen - dielectric $(r=r_э+t)$.

For any n-component of field, we have following system of equations:

$$\left.\begin{aligned} E_z - E_z^0 &= E_z^м \\ H_\varphi + H_\varphi^0 &= H_\varphi^м \end{aligned}\right\} \text{ with } r=r_э, \qquad \left.\begin{aligned} E_z^м &= E_z^0 \\ H_\varphi^м &= H_\varphi^0 \end{aligned}\right\} \text{with } r=r_э+t.$$

Taking into account the values for the electrical and magnetic fields given above it is possible to record:

$$\left.\begin{aligned} E_z(1-P_n) &= C_n J_n(\kappa_м r_э) + D_n K_n(\kappa_м r_э) \\ H_\varphi(1+P_n) &= \frac{\kappa_м}{i\omega\mu}[C_n J_n'(\kappa_м r_э) - D_n K_n'(\kappa_м r_э)] \end{aligned}\right\} \overset{(1)}{\text{при}}\ r=r_э,$$

$$\left.\begin{aligned} E_z S_n &= C_n J_n[\kappa_м(r_э+t)] + D_n K_n[\kappa_м(r_э+t)] \\ H_\varphi S_n &= \frac{\kappa_м}{i\omega\mu}\{C_n J_n'[\kappa_м(r_э+t)] - D_n K_n'[\kappa_м(r_э+t)]\} \end{aligned}\right\} \overset{(1)}{\text{при}}\ r=r_э+t.$$

Key. (1) with.

Utilizing a relationship/ratio between electrical and magnetic fields, derived through wave impedance for a dielectric $(\dot{Z}_д)$ and a metal $(\dot{Z}_м)$, we will obtain:

$$\left.\begin{aligned} &E_z(1-P_n)=C_nJ_n(\kappa_м r_э)+D_nK_n(\kappa_м r_э)\\ &\frac{E_z}{Z_Д^п}+\frac{E_zP_n}{Z_Д^о}=\frac{1}{Z_м}[C_nJ'_n(\kappa_м r_э)-D_nK'_n(\kappa_м r_э)]\end{aligned}\right\}\ \overset{(1)}{\text{при}}\ r=r_э,$$

$$\left.\begin{aligned} &E_zS_n=C_nJ_n[\kappa_м(r_э+t)]+D_nK_n[\kappa_м(r_э+t)]\\ &\frac{E_zS_n}{Z_Д^п}=\frac{1}{Z_м}\{C_nJ'_n[\kappa_м(r_э+t)]-D_nK_n[\kappa_м(r_э+t)]\}\end{aligned}\right\}\ \overset{(1)}{\text{при}}\ r=r_э+t.$$

Key:
(1) with.

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Substituting here the values of wave dielectric resistance for the incident and reflected waves, we will obtain:

$$\left.\begin{aligned} &1.\ E_z(1-P_n)=C_nJ_n(\kappa_м r_э)+D_nK_n(\kappa_м r_э)\\ &2.\ -\frac{E_z}{Z_0\dfrac{H_n(\kappa_Д r_э)}{H'_n(\kappa_Д r_э)}}+\frac{E_zP_n}{Z_0\dfrac{J_n(\kappa_Д r_э)}{J'_n(\kappa_Д r_э)}}=\frac{1}{Z_м}[C_nJ'_n(\kappa_м r_э)-D_nK'_n(\kappa_м r_э)]\end{aligned}\right\}\ \overset{(1)}{\text{при}}\ r=r_э,$$

$$\left.\begin{aligned} &3.\ E_zS_n=C_nJ_n[\kappa_м(r_э+t)]+D_nK_n[\kappa_м(r_э+t)]\\ &4.\ -\frac{E_zS_n}{Z_0\dfrac{H_n(\kappa_Д r_э)}{H'_n(\kappa_Д r_э)}}=\frac{1}{Z_м}\{C_nJ'_n[\kappa_м(r_э+t)]-D_nK'_n[\kappa_м(r_э+t)]\}\end{aligned}\right\}\ \overset{(1)}{\text{при}}\ r=r_э+t.$$

Key: (1) with.

Thus, there is four equations with four unknowns C_n, D_n, S_n, P_n. Store/adding up in pairs expressions (1), (2) and (3), (4) and utilizing recurrence formulae of the cylindrical functions of the first and second kind of composite argument $xI'_n(x)=xI_{n-1}(x)-n\,I_n(x)$ and $xK'_n(x)=-xK_{n-1}(x)-nK_n(x)$, we determine the value of integration constants C_n and D_n. After substituting values C_n and D_n into equ. (3), we obtain the value of screening constant for the transverse magnetic field:

$$S_n=\frac{1}{\kappa_{\text{м}}(r_{\text{э}}+t)\{I_{n-1}(\kappa_{\text{м}}r_{\text{э}})K_n[\kappa_{\text{м}}(r_{\text{э}}+t)]+K_{n-1}(\kappa_{\text{м}}r_{\text{э}})I_n[\kappa_{\text{м}}(r_{\text{э}}+t)]\}}\times$$

$$\times\frac{1}{\left\{1+\dfrac{Z_{\text{м}}^2+Z_0\dfrac{H_n(\kappa_{\text{д}}r_{\text{э}})}{H'_n(\kappa_{\text{д}}r_{\text{э}})}Z_0\dfrac{J_n(\kappa_{\text{д}}r_{\text{э}})}{J'_n(\kappa_{\text{д}}r_{\text{э}})}}{Z_{\text{м}}\left[-Z_0\dfrac{H_n(\kappa_{\text{д}}r_{\text{э}})}{H'_n(\kappa_{\text{д}}r_{\text{э}})}+Z_0\dfrac{J_n(\kappa_{\text{д}}r_{\text{э}})}{J'_n(\kappa_{\text{д}}r_{\text{э}})}\right]}\times\dfrac{I_{n-1}[\kappa_{\text{м}}(r_{\text{э}}+t)]K_{n-1}(\kappa_{\text{м}}r_{\text{э}})-I_{n-1}(\kappa_{\text{м}}r_{\text{э}})K_{n-1}[\kappa_{\text{м}}(r_{\text{э}}+t)]}{I_{n-1}(\kappa_{\text{м}}r_{\text{э}})K_n[\kappa_{\text{м}}(r_{\text{э}}+t)]+K_{n-1}(\kappa_{\text{м}}r_{\text{э}})I_n[\kappa_{\text{м}}(r_{\text{э}}+t)]}\right\}}. \quad (1.23)$$

Utilizing an expansion of cylindrical functions of the type I_n and K_n for a metal with large argument $\kappa_{\text{м}}r_{\text{э}}\geqslant 5$ and $\kappa_{\text{м}}(r_{\text{э}}+t)\geqslant 5$ and applying hyperbolic functions, we obtain expression for a screening constant:

$$S_n = \frac{1}{\operatorname{ch} \kappa_м t} \cdot \frac{1}{1 + \dfrac{Z_м^2 + Z_0^2 \dfrac{J_n(\kappa_д r_э)}{J_n'(\kappa_д r_э)} \dfrac{H_n(\kappa_д r_э)}{H_n'(\kappa_д r_э)}}{Z_м Z_0 \left[\dfrac{J_n(\kappa_д r_э)}{J_n'(\kappa_д r_э)} - \dfrac{H_n(\kappa_д r_э)}{H_n'(\kappa_д r_э)} \right]} \operatorname{th} \kappa_м t}.$$

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After conducting the appropriate transformations, we obtain

$$S_n = \frac{1}{\operatorname{ch} \kappa_м t} \cdot \frac{1}{1 + \left[\dfrac{Z_0}{Z_м} \dfrac{J_n(\kappa_д r_э) H_n(\kappa_д r_э)}{J_n(\kappa_д r_э) H_n'(\kappa_д r_э) - J_n'(\kappa_д r_э) H_n(\kappa_д r_э)} + \dfrac{Z_м}{Z_0} \dfrac{J_n'(\kappa_д r_э) H_n'(\kappa_д r_э)}{J_n(\kappa_д r_э) H_n'(\kappa_д r_э) - J_n'(\kappa_д r_э) H_n(\kappa_д r_э)} \right] \operatorname{th} \kappa_м t},$$

where $\kappa_м = \sqrt{i\omega\mu\sigma}$ is a propagation factor in metal; $\kappa_д = \omega\sqrt{\mu\varepsilon}$ — the same, in dielectric; $Z_м = \sqrt{i\omega\mu/\sigma}$ - wave impedance of metal; $Z_0 = \sqrt{\mu/\varepsilon}$ - the same, dielectric to plane wave; t is thickness of screen; $r_э$ is a radius of screen.

Bearing in mind that wave dielectric resistance Z_0

substantially more the wave impedance of metal Z_{M}, i.e. $Z_0/Z_M \gg Z_M/Z_0$, the second term of the sum of brackets can be disregarded. Physically this is based as follows: the first term of the sum of the brackets corresponds to the reflection of energy on boundary dielectric - screen (in $r=r_э$), andthe second - to reflection at a boundary screen - dielectric (when $r=r_э+t$). With electrically thick screen (attenuation kt > 1.5 Np), which practically always takes place, the role of the second boundary can not be considered. Then the formula of the calculation of the coefficient of screening takes the form

$$S_n = \frac{1}{\operatorname{ch} \kappa_M t} \cdot \frac{1}{1 + \dfrac{Z_0}{Z_M} \cdot \dfrac{J_n(\kappa_Д r_э) H_n(\kappa_Д r_э)}{J_n(\kappa_Д r_э) H_n'(\kappa_Д r_э) - J_n'(\kappa_Д r_э) H_n(\kappa_Д r_э)} \operatorname{th} \kappa_M t}.$$

Using the recurrent relations of cylindrical functions of the first and third kind: $J_n(x)H_n'(x) - J_n'(x)H_n(x) = 2/i\pi x$, we obtain the expression for calculation of the coefficient of screening of the magnetic field in the following form:

$$S = \frac{1}{\operatorname{ch} \kappa_M t} \cdot \frac{1}{1 + \dfrac{1}{2} \dfrac{Z_0}{Z_M} i\pi \kappa_Д r_э J_n(\kappa_Д r_э) H_n(\kappa_Д r_э) \operatorname{th} \kappa_M t}. \quad (1.24)$$

In the technology of communication and electronics, it is accepted to evaluate the screens not in terms of the coefficient of screening S, but in terms of the attenuation of screening $A_э$, which characterizes the magnitude of attenuation (in decibels or nepers) introduced by the screen (1 dB=0.115 Np;

1 Np = 8.686 dB, see appendix 1): $A_{\text{э}}=20\lg\left|\frac{1}{S}\right|$, dB, or $A_{\text{э}}=\ln\left|\frac{1}{S}\right|$, Np. Then for fundamental component magnetic field (n = 1) the attenuation of shadowing is determined by the formula

$$A_{\text{э}}^{\text{н}}=\ln\left|\frac{1}{S}\right|=\ln|\operatorname{ch}\kappa_{\text{м}}t|+\ln\left|1+\frac{1}{2}\frac{Z_0}{Z_{\text{м}}}i\pi\kappa_{\text{д}}r_{\text{э}}J_1(\kappa_{\text{д}}r_{\text{э}})H_1(\kappa_{\text{д}}r_{\text{э}})\operatorname{th}\kappa_{\text{м}}t\right|. \tag{1.25}$$

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1.3. Shadowing of electric field.

In this case it is to operate with transverse electrical wave TE. Perturbation source is the longitudinal operating magnetic wave H_z, which it creates cross field E_{φ}, being subject to shadowing (Fig. 1.1b). Let us examine action of screen relative to this field.

For the solution to stated problem first of all, let us determine the value of component magnetic H_z and electrical E_φ fields. The value of the wave impedance, exerted to the radially directed energy flow, will be determined through these components: $Z_r = E_\varphi / H_z$.

The equation of Maxwell in cylindrical coordinate system relatively H_z (without taking into account of change along screen) takes the form

$$\frac{\partial^2 H_z}{\partial r^2} + \frac{1}{r}\frac{\partial H_z}{\partial r} + \frac{1}{r^2}\frac{\partial^2 H_z}{\partial \varphi^2} = \begin{cases} \kappa_{м}^2 H_z - \text{ FOR METAL,} \\ -\kappa_{д}^2 H_z - \text{ for a dielectric,} \end{cases}$$

where $\kappa_{м} = \sqrt{i\omega\mu\sigma}$ is a propagation factor in metal; $\kappa_{д} = \omega\sqrt{\mu\varepsilon}$ - propagation factor in dielectric.

The solution to this equation for a dielectric takes the form

$$H_z = \sum_{n=0}^{\infty} [A_n J_n(\kappa_{д} r) + B_n H_n(\kappa_{д} r)] \cos n\varphi, \qquad (1.26)$$

where J_n and H_n are cylindrical functions of the first (Bessel) and third (Hankel) kind; A_n and B_n are integration

constant; r and ϕ - radial and tangential coordinates.

According to equ. (1.7) we determine the second E_φ: component

$$E_\varphi = -\frac{1}{i\omega\varepsilon}\frac{\partial H_z}{\partial r} = -\frac{\kappa_д}{i\omega\varepsilon}\sum_{n=0}^{\infty}[A_n J'_n(\kappa_д r) - B_n H'_n(\kappa_д r)]\cos n\varphi. \quad (1.27)$$

In expressions (1.26) and (1.27) the first members, who increase with increase in r, characterize the waves (H_z^o and E_φ^o), reflected a the second members, who decrease with increase in r, the incident waves (H_z^n and E_φ^n) When $r \leqslant r_0$

$$H_z^n = \sum_{n=0}^{\infty} B_n H_n(\kappa_д r)\cos n\varphi,$$

$$E_\varphi^n = \frac{\kappa_д}{i\omega\varepsilon}\sum_{n=0}^{\infty} B_n H'_n(\kappa_д r)\cos n\varphi,$$

$$H_z^o = \sum_{n=0}^{\infty} A_n J_n(\kappa_д r)\cos n\varphi,$$

$$E_\varphi^o = -\frac{\kappa_д}{i\omega\varepsilon}\sum_{n=0}^{\infty} A_n J'_n(\kappa_д r)\cos n\varphi,$$

where $Z_0 = \frac{\kappa_д}{i\omega\varepsilon} = \frac{i\omega\sqrt{\mu\varepsilon}}{i\omega\varepsilon} = \sqrt{\frac{\mu}{\varepsilon}} = \rightarrow 376{,}7$ (ohm) is the wave dielectric resistance, exerted to plane wave.

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With respect is determined wave dielectric resistance for the incident and reflected waves of any n-component:

$$\left.\begin{aligned} Z_{д}^{п} &= \frac{E_{\varphi}^{п}}{H_{z}^{п}} = Z_{0}\frac{H_{n}'(\kappa_{д}r)}{H_{n}(\kappa_{д}r)} \\ Z_{д}^{о} &= \frac{E_{\varphi}}{H_{z}^{о}} = -Z_{0}\frac{J_{n}'(\kappa_{д}r)}{J_{n}(\kappa_{д}r)} \end{aligned}\right\}. \qquad (1.28)$$

Comparing the obtained values -'$Z_{д}^{п}$ and $Z_{д}^{о}$ with analogous values for the case of the transverse magnetic field, we see that the functions J_n and H_n and their derivatives J_n' and H_n' were changed by places in numerator and denominator.

Let us determine now value H_z, E_{φ} and respectively wave impedance for a metal $Z_м$. The solution to the equation of Maxwell for the conducting medium with coefficient $\kappa_м$ takes the form:

$$H_z = \sum_{n=0}^{\infty} [C_n I_n(\kappa_M r) + D_n K_n(\kappa_M r)] \cos n\varphi, \qquad (1.29)$$

$$E_\varphi = -\frac{1}{\sigma}\frac{\partial H_z}{\partial r} = -\frac{\kappa_M}{\sigma}\sum_{n=0}^{\infty} [C_n I'_n(\kappa_M r) - D_n K'_n(\kappa_M r)] \cos n\varphi, \qquad (1.30)$$

where I_n and K_n - the modified cylindrical functions of the first (Bessel) and second (Neumann) kind of composite argument; C_n and D_n - integration constant; r and ϕ - moving coordinates.

Respectively electrical and magnetic fields for the incident and reflected waves will be:

$$H_z^{\pi} = \sum_{n=0}^{\infty} D_n K_n(\kappa_M r) \cos n\varphi,$$

$$E_\varphi^{\pi} = \frac{\kappa_M}{\sigma}\sum_{n=0}^{\infty} D_n K'_n(\kappa_M r) \cos n\varphi,$$

$$H_z^{o} = \sum_{n=0}^{\infty} C_n I_n(\kappa_M r) \cos n\varphi,$$

$$E_\varphi^{o} = -\frac{\kappa_M}{\sigma}\sum_{n=0}^{\infty} C_n I'_n(\kappa_M r) \cos n\varphi.$$

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Here $Z_м = \kappa_м/\sigma = \sqrt{i\omega\mu\sigma}/\sigma = \sqrt{i\omega\mu/\sigma}$ is wave impedance of metal to plane wave.

As a result we will obtain the values of the wave impedance of the conducting medium for any n-component the incident and reflected waves:

$$\left.\begin{aligned} Z_м^п &= \frac{E_\varphi^п}{H_z^п} = Z_м \frac{K_n'(\kappa_м r)}{K_n(\kappa_м r)} \\ Z_м^о &= \frac{E_\varphi^о}{H_z^о} = -Z_м \frac{I_n'(\kappa_м r)}{I_n(\kappa_м r)} \end{aligned}\right\}. \tag{1.31}$$

In the range of high frequencies with the value of argument $\kappa_м r \geqslant 5$ and the relationship/ratio of the cylindrical functions

$$\frac{I_n(\kappa_м r)}{I_n'(\kappa_м r)} \to 1 \quad \text{AND} \quad и \quad \frac{K_n(\kappa_м r)}{K_n'(\kappa_м r)} \to -1$$

we will obtain for the conducting medium:

$$\left.\begin{aligned} Z_м^п &= Z_м = \sqrt{\frac{i\omega\mu}{\sigma}} \\ Z_м^о &= -Z_м = -\sqrt{\frac{i\omega\mu}{\sigma}} \end{aligned}\right\}. \tag{1.32}$$

Wave impedance for the incident and reflected waves is characterized by only signs, which indicates the contrast of the direction of the motion of these waves.

Let us examine electromagnetic fields, which operate inside and outside tap/crane, and also in it is thicker than the screen (Fig. 1.2a).

In region I within screen, operate the incident and reflected fields: electrical $E_{\varphi}^{n}+E_{\varphi}^{o}$, magnetic $H_{z}^{n}-H_{z}^{o}$.

The field reflected we express as the coefficient of the reaction of screen P_n:

$$\left.\begin{aligned} H_z^n-H_z^n P_n=H_z^n(1-P_n)=H_z(1-P_n) \\ E_{\varphi}^n+E_{\varphi}^n P_n=E_{\varphi}^n(1+P_n)=E_{\varphi}(1+P_n) \end{aligned}\right\}. \quad (1.33)$$

where H_z and E_{φ} - the components of the electrical and magnetic fields of perturbation source.

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In region III, outside screen electromagnetic field is expressed as the screening constant S_n characterizing the ratio of field in any point of space in the presence of screen ($H_z^э$ and $E_\varphi^э$) to field in this same point without screen (H_z and E_φ):

$$\left.\begin{aligned} H_z^э &= H_z S_n \\ E_\varphi^э &= E_\varphi S_n \end{aligned}\right\}. \tag{1.34}$$

In region II in thicker than the screen will operate the fields

$$\left.\begin{aligned} H_z &= H_z^м \\ E_\varphi &= E_\varphi^м \end{aligned}\right\}, \tag{1.35}$$

For the solution to stated problem and, in the first place, the determinations of integration constants and interesting us the screening constant S_n and of the coefficient of the reaction of screen p_n we will use the continuity condition of tangential components H_z and E_φ fields on the interface of mediums dielectric - screen $(r=r_э)$ and screen - dielectric $(r=r_э+t)$. Then we obtain following system of equations:

$$\left.\begin{aligned} H_z - H_z^0 &= H_z^м \\ E_\varphi + E_\varphi^0 &= E_\varphi^м \end{aligned}\right\} \text{ WITH } r = r_э,$$

$$\left.\begin{aligned} H_z^м &= H_z^э \\ E_\varphi^м &= E_\varphi^э \end{aligned}\right\} \text{ with. } r = r_э + t.$$

Taking into account the above-obtained values for the electrical and magnetic fields of equation for any n-component, they take the form:

$$\left.\begin{aligned} H_z(1-P_n) &= C_n I_n(\kappa_м r_э) + D_n K_n(\kappa_м r_э) \\ E_\varphi(1+P_n) &= -\frac{\kappa_м}{\sigma}[C_n I'_n(\kappa_м r_э) - D_n K'_n(\kappa_м r_э)] \end{aligned}\right\} \text{ WITH } r = r_э,$$

$$\left.\begin{aligned} H_z S_n &= C_n I_n[\kappa_м(r_э+t)] + D_n K_n[\kappa_м(r_э+t)] \\ E_\varphi S_n &= -\frac{\kappa_м}{\sigma}\{C_n I'_n[\kappa_м(r_э+t)] - D_n K'_n[\kappa_м(r_э+t)]\} \end{aligned}\right\} \text{ with. } r = r_э + t.$$

Utilizing formulas of wave impedance $Z_д$ and $Z_м$, we will obtain:

$$\left.\begin{array}{r} H_z(1-P_n)=C_n I_n(\kappa_м r_э)+D_n K_n(\kappa_м r_э) \\ H_z Z_д^п+H_z Z_д^о P_n=-Z_м[C_n I'_n(\kappa_м r_э)+D_n K'_n(\kappa_м r_э)] \end{array}\right\} \overset{(1)}{\text{при}}\ r=r_э,$$

$$\left.\begin{array}{r} H_z S_n=C_n I_n[\kappa_м(r_э+t)]+D_n K_n(\kappa_м(r_э+t)] \\ H_z Z_д^п S_n=-Z_м\{C_n I'_n[\kappa_м(r_э+t)]-D_n K'_n[\kappa_м(r_э+t)]\} \end{array}\right\} \overset{(1)}{\text{при}}\ r=r_э+t.$$

Key: (1) with.

Substituting here the values of wave dielectric resistance for the incident and reflected wave, we will obtain:

$$\left.\begin{array}{l} 1.\ H_z(1-P_n)=C_n I_n(\kappa_м r_э)+D_n K_n(\kappa_м r_э) \\ 2.\ H_z Z_0\dfrac{H'_n(\kappa_д r_э)}{H_n(\kappa_д r_э)}-H_z Z_0\dfrac{J'_n(\kappa_д r_э)}{J_n(\kappa_д r_э)}P_n=-Z_м[C_n I'_n(\kappa_м r_э)-D_n K'_n(\kappa_м r_э)] \end{array}\right\}$$
$$(1)\ \text{при}\ r=r_э,$$

$$\left.\begin{array}{l} 3.\ H_z S_n=C_n I_n[\kappa_м(r_э+t)]+D_n K_n[\kappa_м(r_э+t)] \\ 4.\ H_z Z_0\dfrac{H'_n(\kappa_д r_э)}{H_n(\kappa_д r_э)}S_n=-\{C_n I'_n[\kappa_м(r_э+t)]-D_n K'_n[\kappa_м(r_э+t)]\} \end{array}\right\} \overset{(1)}{\text{при}}\ r=r_э+t.$$

Key: (1) with.

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Thus, we have four equations with four unknowns: C_n, D_n, S_n, P_n. Store up in pairs expressions (1), (2) and

(3), (4) and utilizing recurrence formulae of the cylindrical functions of the first and second kind of composite argument $xI_n'(x) \approx xI_{n-1}(x) - nI_n(x)$ and $xK_n'(x) = -xK_{n-1}(x) - nK_n(x)$,

let us determine the values of integration constants C_n and D_n. After substituting values C_n and D_n into equ. (3), we will obtain screening constant for the transverse electrical field:

$$S_n = \frac{1}{\kappa_{\text{м}}(r_{\text{э}}+t)\left\{I_{n-1}(\kappa_{\text{м}}r_{\text{э}})K_n[\kappa_{\text{м}}(r_{\text{э}}+t)] + K_{n-1}(\kappa_{\text{м}}r_{\text{э}})I_n[\kappa_{\text{м}}(r_{\text{э}}+t)]\right\}} \times$$

$$\times \frac{1}{\left\{1 + \dfrac{Z_{\text{м}}^2 + Z_0 \dfrac{H_n'(\kappa_{\text{д}}r_{\text{э}})}{H_n(\kappa_{\text{д}}r_{\text{э}})} Z_0 \dfrac{J_n'(\kappa_{\text{д}}r_{\text{э}})}{J_n(\kappa_{\text{д}}r_{\text{э}})}}{Z_{\text{м}}\left[-Z_0 \dfrac{H_n'(\kappa_{\text{д}}r_{\text{э}})}{H_n(\kappa_{\text{д}}r_{\text{э}})} + Z_0 \dfrac{J_n'(\kappa_{\text{д}}r_{\text{э}})}{J_n(\kappa_{\text{д}}r_{\text{э}})}\right.} \times \rightarrow\right.}$$

$$\left.\rightarrow \times \frac{I_{n-1}[\kappa_{\text{м}}(r_{\text{э}}+t)]K_{n-1}(\kappa_{\text{м}}r_{\text{э}}) - I_{n-1}(\kappa_{\text{м}}r_{\text{э}})K_{n-1}[\kappa_{\text{м}}(r_{\text{э}}+t)]}{I_{n-1}(\kappa_{\text{м}}r_{\text{э}})K_n[\kappa_{\text{м}}(r_{\text{э}}+t)] + K_{n-1}(\kappa_{\text{м}}r_{\text{э}})I_n[\kappa_{\text{м}}(r_{\text{э}}+t)]}\right\}. \quad (1.36)$$

Utilizing an expansion of cylindrical functions J_n and K_n for a metal with large argument $\kappa_{\text{м}}r_{\text{э}} \geqslant 5$ and $\kappa_{\text{м}}(r_{\text{э}}+t) \geqslant 5$ and applying hyperbolic functions, we will obtain expression for a screening constant

$$S_n=\frac{1}{\mathrm{ch}\,\kappa_{\text{м}}t}\,\frac{1}{1+\dfrac{Z_{\text{м}}^2+Z_0^2\,\dfrac{H_n'(\kappa_{\text{д}}r_{\text{э}})}{H_n(\kappa_{\text{д}}r_{\text{э}})}\,\dfrac{J_n'(\kappa_{\text{д}}r_{\text{э}})}{J_n(\kappa_{\text{д}}r_{\text{э}})}}{Z_{\text{м}}Z_0\left[\dfrac{J_n'(\kappa_{\text{д}}r_{\text{э}})}{J_n(\kappa_{\text{д}}r_{\text{э}})}-\dfrac{H_n'(\kappa_{\text{д}}r_{\text{э}})}{H_n(\kappa_{\text{д}}r_{\text{э}})}\right]}\,\mathrm{th}\,\kappa_{\text{м}}t}.$$

After conducting the appropriate transformations, we will obtain

$$S_n=\frac{1}{\mathrm{ch}\,\kappa_{\text{м}}t}\,\frac{1}{1+\left[\dfrac{Z_0}{Z_{\text{м}}}\,\dfrac{J_n'(\kappa_{\text{д}}r_{\text{э}})\,H_n'(\kappa_{\text{д}}r_{\text{э}})}{J_n(\kappa_{\text{д}}r_{\text{э}})H_n'(\kappa_{\text{д}}r_{\text{э}})-J_n'(\kappa_{\text{д}}r_{\text{э}})H_n(\kappa_{\text{д}}r_{\text{э}})}+\dfrac{Z_{\text{м}}}{Z_0}\,\dfrac{J_n(\kappa_{\text{д}}r_{\text{э}})\,H_n(\kappa_{\text{д}}r_{\text{э}})}{J_n(\kappa_{\text{д}}r_{\text{э}})\,H_n'(\kappa_{\text{д}}r_{\text{э}})-J_n'(\kappa_{\text{д}}r_{\text{э}})\,H_n(\kappa_{\text{д}}r_{\text{э}})}\right]\mathrm{th}\,\kappa_{\text{м}}t},$$

where $\kappa_{\text{м}}=\sqrt{i\omega\mu\sigma}$ is a propagation factor in metal; $\kappa_{\text{д}}=\omega\sqrt{\mu\varepsilon}$ - the same, in dielectric; $Z_{\text{м}}=\sqrt{i\omega\mu/\sigma}$ - wave impedance of metal; $Z_0=\sqrt{\mu/\varepsilon}$ - the same, dielectric to plane wave; t is thickness of screen; $r_{\text{э}}$ is a radius of screen.

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Since wave dielectric resistance Z_0 substantially more

the wave impedance of metal $Z_м$ (especially for the nonmagnetic materials), i.e., $\frac{Z_0}{Z_м} \gg \frac{Z_м}{Z_0}$ it is possible to disregard the second term of the sum of brackets. Physically this means that with electrically thick screen ($\kappa t > 1{,}5$ Np) the role of the second boundary can be not considered. Then the formula of the calculation of screening constant will take the form

$$S_n = \frac{1}{\operatorname{ch} \kappa_м t} \cdot \frac{1}{1 + \frac{Z_0}{Z_м} \cdot \frac{J'_n(\kappa_д r_э) H'_n(\kappa_д r_э)}{J_n(\kappa_д r_э) H'_n(\kappa_д r_э) - J'_n(\kappa_д r_э) H_n(\kappa_д r_э)} \operatorname{th} \kappa_м t} \cdot \cdot$$

Utilizing recurrence formulae of the cylindrical functions of the first and third kind $J_n(x)H'_n(x) - J'_n(x)H_n(x) = \frac{2}{i\pi x}$, we will obtain expression for the calculation of the screening constant of the electric field:

$$S_n = \frac{1}{\operatorname{ch} \kappa_м t} \cdot \frac{1}{1 + \frac{1}{2} \frac{Z_0}{Z_м} i \pi \kappa_д r_э J'_n(\kappa_д r_э) H'_n(\kappa_д r_э) \operatorname{th} \kappa_м t} \cdot \quad (1.37)$$

Expressing the shielding properties through the parameter of the attenuation of shadowing $A_э$ (in nepers), we will obtain for fundamental component electric field (n = 1)

$$A_э^E = \ln \left| \frac{1}{S_1} \right| = \ln |\operatorname{ch} \kappa_м t| + \ln \left| 1 + \frac{1}{2} \frac{Z_0}{Z_м} i \pi \kappa_д r_э J'_n(\kappa_д r_э) H'_n(\kappa_д r_э) \operatorname{th} \kappa_м t \right|. \quad (1.38)$$

1.4. Single method of the calculation of screens over a wide range of frequencies.

Analyzing the obtained results, it is possible to note that the formulas for the calculation of screens of the relatively magnetic field, caused by the transverse magnetic wave TM, and the electric field, caused by transverse electrical wave TE, have in principle identical structure [see expressions (1.25) and (1.38)].

This makes it possible to accept the single formula of the calculation of the attenuation of the shadowing of magnetic and electric fields in the following form:

$$A_э = \ln|\mathrm{ch}\,\kappa_м t| + \ln\left|1 + \frac{1}{2}\frac{Z_д}{Z_м}\mathrm{th}\,\kappa_м t\right|. \qquad (1.39)$$

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The difference will be only in the values of wave dielectric resistance $Z_д$:

for a magnetic field (wave TM)

$$Z_д^H = Z_0\, i\,\pi\kappa_д r_э I_1(\kappa_д r_э) H_1(\kappa_д r_э), \qquad (1.40)$$

for an electric field (wave TE)

$$Z_{\text{д}}^{E} = Z_{0}\, i\, \pi\, \kappa_{\text{д}} r_{э}\, I_{1}'(\kappa_{\text{д}} r_{э})\, H_{1}'(\kappa_{\text{д}} r_{э}). \quad (1.41)$$

The remaining values, which relate directly to the metal of screen, are identical for the electrical and magnetic fields: $\kappa_{\text{м}} = \sqrt{i\omega\mu\sigma}$ is a propagation factor in metal; $Z_{\text{м}} = \sqrt{i\omega\mu/\sigma}$ - wave impedance of metal; t is thickness of screen.

Formula (1.39) is valid for the calculation of the attenuation of shadowing over a wide range of frequencies (from zero to SHF), also, during any mode/conditions of the use of screens (electromagnetostatic, electromagnetic, wave). Analyzing the obtained result, it can be noted that formula (1.39) consists of two parts: $\ln|\operatorname{ch} \kappa_{\text{м}} t| = A_{\text{п}}$ are attenuations of absorption and $\ln\left|1 + \frac{1}{2}\frac{Z_{\text{д}}}{Z_{\text{м}}} \operatorname{th} \kappa_{\text{м}} t\right| = A_{\text{o}}$ - attenuation of reflection. $A_{\text{п}}$ caused by thermal eddy current losses in the metal of screen and it will be the greater, the higher the frequency and is thicker the screen. A_0 is connected with the nonconformity of the wave characteristics of the metal from which is made the screen ($Z_{\text{м}}$), and the dielectric, which surrounds screen ($Z_{\text{д}}$): the greater the difference among $Z_{\text{д}}$ and $Z_{\text{м}}$, the more powerful the effect of the attenuation of reflection.

Attenuation length of absorption $A_п$ dces not in practice depend on the form of field and has single-valued value for entire frequency band from zerc to SHF. The attenuation of reflection A_0, primarily wave dielectric resistance $Z_д$ is different for the different mode/conditions of the frequency ranges of the use of a screen.

Let us examine the values of wave dielectric resistance for the magnetic $(Z^H_д)$ and electrical $(Z^E_д)$ of fields. The formula of calculation $Z^H_д$ contains the product of the cylindrical functions I_1 H_1 while the formula of calculation $Z^E_д$ is a product of the derived these functions I'_1 H'_1. Functions have an oscillatory nature, also, with the argument, equal to zero, product $I_1H_1 \rightarrow 0$, and product $I'_1H'_1 \rightarrow \infty$. With a small argument $(x < 0.25)$ of function I_1 and H_1, they are converted: $I_1(x) = x/2$ and $H_1(x) = i\left(2/\pi x\right)$. Then wave resistance of the dielectric of relatively magnetic and electric fields accept the substantially simpler form:

$$\left.\begin{aligned} Z_{\text{д}}^{H} &= Z_0 i \kappa_{\text{д}} r_0 = \sqrt{\frac{\mu}{\varepsilon}} i\omega\sqrt{\mu\varepsilon}\, r_0 = i\omega\mu r_0 \\ Z_{\text{д}}^{E} &= Z_0 \frac{1}{i\kappa_{\text{д}} r_0} = \sqrt{\frac{\mu}{\varepsilon}} \cdot \frac{1}{i\omega\sqrt{\mu\varepsilon}\, r_0} = \frac{1}{i\omega\varepsilon r_0} \end{aligned}\right\} \qquad (1.42)$$

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According to formulas (1.42) it is possible to conduct the calculation of wave dielectric resistance in the range of frequencies approximately to 10^8-10^9 Hz. By this same formulas it is possible to perform the calculation of screens with the preferred effect of electrical the calculation of screens with the preferred effect of electrical or magnetic field. For a plane wave in free space, wave dielectric resistance is equal to

$$Z_0 = Z_{\text{д}}^{EH} = \sqrt{\frac{\mu}{\varepsilon}} = 376{,}7 \text{ ohm}.$$

To Fig. 1.3, is shown the standard frequency dependence of wave dielectric resistance of relatively electrical and magnetic fields, and also the wave impedance of plane wave (Z_0) and the wave impedance of metal ($Z_{\text{м}}$). From the given formulas and figure, it is evident that the frequency dependence of wave dielectric resistance for magnetic and

electric fields has in principle different character. Value $Z_{\text{д}}^{H}$ - increases, a $Z_{\text{д}}^{E}$ having infinity with f = 0, it falls. In absolute value $Z_{\text{д}}^{E} > Z_0 > Z_{\text{д}}^{H}$ In the wave zone (at frequencies more than 10^9 Hz) of value $Z_{\text{д}}^{H}$ and $Z_{\text{д}}^{E}$ they have an oscillatory nature. The wave impedance of metal $Z_{\text{м}}$ increases according to the law of root from frequency, while the wave impedance of the plane wave Z_0 is constant.

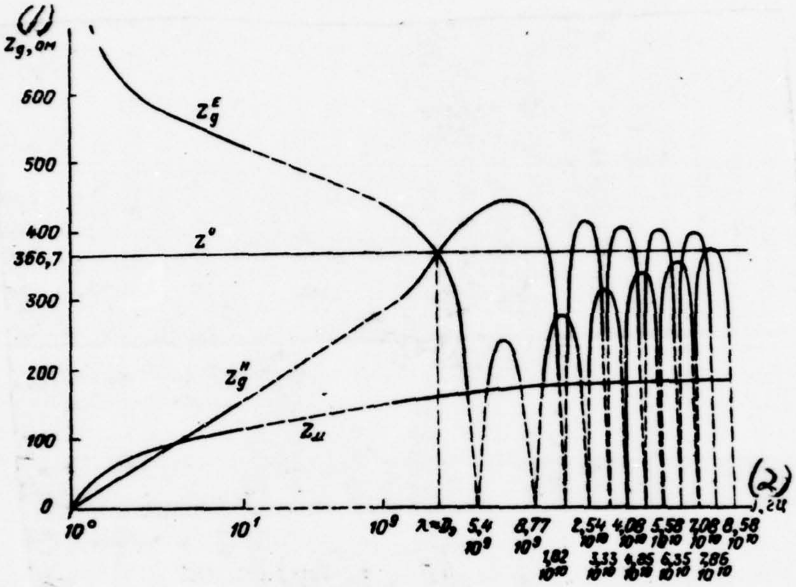

Fig. 1.3. Frequency dependence of wave dielectric resistance relative to the magnetic wave (Z^H_H) electrical wave (Z^E_H) of plane wave (Z_0) and the wave resistor/resistance of metal (Z_M).

Key: (1). ohm. (2). Hz.

[redacted]

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The frequency dependences of the attenuation of the reflection of magnetic field (A_o^H) and of the attenuation of the reflection of electric field (A_o^E) are analogous to dependences $Z_Д^H$ and $Z_Д^E$ respectively.

Figures 1.4a and b gives the results of the calculation of the attenuation of the shadowing of the magnetic $A_э^H$ and electrical $A_э^E$ of fields. On curve/graphs are visible three characteristic frequency domains, which correspond to the different mode/conditions of the work of the screens: I - low-frequency range (L.F.) corresponding to the electrostatic and magnetostatic operating modes; II - high-frequency range (to h.f.), that corresponds electromagnetic mode/conditions; III - superhigh-frequency range (SHF [superhigh frequency]), that corresponds wave mode/conditions.

The electrostatic and magnetostatic operating mode are based on the principle of the closing/shorting of charges

(electrostatics) or power lines (magnetostatics) in the metal of screen. Any grounded metal screen operating in electrostatic mode/conditions, and ferromagnetic (steel) screen - in magnetostatic.

These mode/conditions encompass frequency range from zero to several kilohertz and can be expressed by the equations of Maxwell for permanent field: rot $H = \sigma E$, rot $E = 0$.

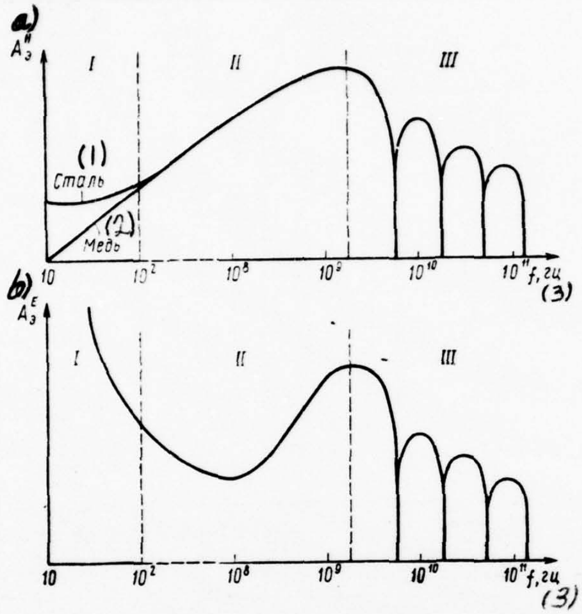

Fig. 1.4. Frequency dependences of attenuation of shadowing of magnetic A_A^H (a) and electrical A_A^E (b).

Key: (1). steel. (2). Copper. (3). Hz.

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Differences in the electrostatic and magnetostatic mode/conditions consist of following. Magnetostatic mode/conditions gives comparatively small and in practice

identical screening effect in all frequency band (from zero to 10^4 Hz). In this frequency range magnetic screen operates on the principle of the closing/shorting of magnetic field in thicker than the screen as a result of its increased magnetopermeability. With an increase of frequency, grow/rises the role of eddy currents, occurs the displacement of magnetic field from the thickness of screen and screen passes to the electromagnetic operating mode.

Electrostatic mode/conditions gives screening effect, equal to infinity in stationary field (f = 0). With an increase of frequency, it grow/rises the role of eddy currents and electrostatic mode/conditions passes to electromagnetic, that operates because of eddy currents in thicker than the screen. Therefore screening effect (Fig. 1.4b) with f = 0 is equal to infinity, then rapidly it descends, having a minimum at frequency of approximately 10^4 Hz, and then smoothly it grow/rises. Minimum screening effect corresponds to the transition of the mode/conditions of shadowing from electrostatic to electromagnetic.

In electromagnetostatic mode/conditions of absorption loss in metal ($A_{\text{п}}$) are small, and it is possible not to consider them.

The electromagnetic mode/conditions of the work of screens is based on the action of eddy currents in thicker than screens. Electromagnetic shadowing can be represented as absorption and the multiple reflection of electromagnetic energy from the metallic thickness of screen. The reflection of energy is connected with the nonconformity of the wave (A_0) characteristics of the metal from which is made the screen, and the dielectric, which surrounds screen.

The attenuation of energy in screen is caused by thermal eddy current losses in metal, and the more powerful the eddy currents, the greater the energy absorption in screen and is more the value of screen attenuation because of absorption ($A_п$).

The electromagnetic mode/conditions of shadowing (h.f.) encompasses frequency range from 10^3-10^4 to 10^8-10^9 Hz. At high frequencies, when wavelength becomes commensurable with the size/dimensions of screen, they appear wave processes and electromagnetic mode/conditions it passes to wave mode/conditions. For this frequency domain are valid the equations of Maxwell in quasi-stationary mode/conditions

(without taking into account of bias currents): rot H = $\sigma\dot{E}$, rot $\dot{E}$ = $-i\omega\mu\dot{H}$, and also previously obtained formulas of the attenuation of shadowing $A_э^H$ and $A_э^E$. The calculation of wave dielectric resistance $Z_д$ is conducted by the simplified formulas: $Z_д^H = i\omega\mu r_э$ and $Z_д^E = \frac{1}{i\omega\varepsilon r_э}$.

The wave mode/conditions of the work of screen is related to the range of superhigh frequencies from 10^9 Hz and it is above. This mode/conditions sets in with the waves, commensurable with the transverse size/dimensions of screen ($\lambda \leqslant D_э$).

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In this case the calculation of screens one should produce the complete equations of the electrodynamics: rot $\dot{H} = \sigma\dot{E} + i\omega\varepsilon\dot{E}$ and rot $\dot{E}$ = $-i\omega\mu\dot{H}$, taking into account also bias currents. In this case it is possible to use to formulas (1.25) and (1.38) taking into account expressions (1.40) and (1.41). A vital difference in the screening effect in this range from the range of lower frequencies is in fluctuating wavelike nature of change $A_э$ from frequency. Figures 1.4a and b shows that, beginning with frequency 10^{10} Hz, that corresponds to condition $\lambda \leqslant D_э$, characteristic it has an

oscillatory nature of a change in the attenuation of shadowing. Physically this is explained by the wave nature of the field of SHF. Mathematically it is connected with the presence in the formulas of the calculation $A_э$ of the cylindrical functions of first and third order $[I_1(\kappa_д r_э)$ and $H_1(\kappa_д r_э)]$, which are given to attenuation an oscillatory nature. Failures in the fixed points, which correspond to the zero coordinates of function $I_1(\kappa_д r_э)$, reach ∞. For example, for wave TM resonance begins when $D_э/\lambda = 1{,}22;\ 2{,}234;\ 3{,}238$ so forth. Resonance phenomena are characteristic both for transverse-magnetic field (TM) and transverse electrical field (TE). Difference only in the values of resonance frequencies.

The mathematical difference between the processes of the shadowing of fields TM and TE is caused by the facts that in the first case in formula figure as the functions $I_1(\kappa_д r_э)$ and $H_1(\kappa_д r_э)$, but in the second - derived of these functions $I_1'(\kappa_д r_э)$ and $H_1'(\kappa_д r_э)$. With f ⟶ ∞ the product $I_1(\kappa_д r_э) H_1(\kappa_д r_э)$ gives zero and therefore with f = 0 for a magnetic field $A_э = 0$, a $I_1'(\kappa_д r_э) H_1'(\kappa_д r_э)$ gives infinity and therefore with f = 0 for an electric field $A_э \to \infty$. To this is explained also the nonconformity of the resonance frequencies of the attenuation of shadowing for fields TE and TM in wave range.

Let us examine in more detail fundamental characteristics and the laws governing screens in the different mode/conditions of their use: electromagnetostatic, electromagnetic and wave.

11.5. Magnetostatic and electrostatic shadowing.

Electromagnetostatic mode/conditions is related to stationary and permanent fields and in connection with the objects of shadowing in question it encompasses the DC fields and tone frequency band (to 4 kHz). For determining the characteristics of screens in electrostatic and magnetostatic mode/conditions, we convert and it is simplified the formula

$$A_{\text{э}} = A_{\text{п}} + A_{\text{о}} = \ln|\mathrm{ch}\,\kappa_{\text{м}} t| + \ln\left|1 + \frac{1}{2}\left(\frac{Z_{\text{д}}}{Z_{\text{м}}} + \frac{Z_{\text{м}}}{Z_{\text{д}}}\right)\mathrm{th}\,\kappa_{\text{м}} t\right|,$$

where $Z_{\text{д}}$ - the wave dielectric resistance, respectively equal for an electric field $Z_{\text{д}}^{E} = \frac{1}{i\omega\varepsilon r_{\text{э}}}$, for a magnetic field $Z_{\text{д}}^{H} = i\omega\mu r_{\text{э}}$ and a plane wave $Z_0 = \sqrt{\frac{\mu}{\varepsilon}}$.

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During the use of a screen in static behavior, it is necessary to consider both boundaries of reflection: dielectric - screen $(Z_д/Z_м)$ and screen - dielectric $(Z_м/Z_д)$. For direct current and low frequencies (to 10^3 Hz) the attenuation of energy in is thicker than the screen very little. In this frequency zone $\kappa_м t \leqslant 0{,}25$, $\operatorname{ch}\kappa_м t \to 1$ and $A_п \to 0$, i.e., losses of energy in thickness of screen can be not considered. Furthermore, $\operatorname{th}\kappa_м t \approx \kappa_м t$. Hence $A_э = A_o = \ln\left|1 + \frac{1}{2}\left(\frac{Z_д}{Z_м} + \frac{Z_м}{Z_д}\right)\kappa t\right|$.

Let us examine separately the attenuation of shadowing for electrostatic and magnetostatic fields.

For an electrostatic field.

In this case $\frac{Z_д^E}{Z_м} \gg \frac{Z_м}{Z_д^E}$ and then

$$A_э^E = \ln\left|1 + \frac{1}{2}\frac{Z_д^E}{Z_м}\kappa_м t\right| \qquad (1.43)$$

or

$$A_э^E = \ln\left|1 + \frac{1}{2} Z_д^E \sigma t\right|,$$

where $Z_д^E = 1/i\omega\varepsilon r_э$; σ - the conductivity of metal.

For a magnetostatic field.

In this case it is necessary to consider the special feature/peculiarity of the shadowing of the nonmagnetic (copper, aluminum, lead) and magnetic (steel, Permalloy, ferrite) screens for which $\frac{Z_{\text{д}}^{H}}{Z_{\text{м}}} > \frac{Z_{\text{м}}}{Z_{\text{д}}^{H}}$ and $\frac{Z_{\text{м}}}{Z_{\text{д}}^{H}} > \frac{Z_{\text{д}}^{H}}{Z_{\text{м}}}$ respectively. Then we obtain:

for magnetic screens

$$A_{\text{э}}^{H} = \ln\left|1 + \frac{1}{2}\frac{Z_{\text{м}}}{Z_{\text{д}}^{H}}\kappa_{\text{м}} t\right| = \ln\left|1 + \frac{\mu t}{2r_{\text{э}}}\right|, \qquad (1.44)$$

where μ - relative magnetic permeability (for steel μ = 100);

for nonmagnetic screens

$$A_{\text{э}}^{H} = \ln\left|1 + \frac{1}{2}\frac{Z_{\text{д}}^{H}}{Z_{\text{м}}}\kappa_{\text{м}} t\right| = \ln\left|1 + \frac{\kappa_{\text{м}}^{2} r_{\text{э}} t}{2}\right|. \qquad (1.45)$$

For a plane wave.

In this case for low frequencies always $Z_0 > Z_{\text{м}}$, and therefore the formula of the calculation of the attenuation of shadowing will be simplified to the form

$$A_{\text{э}}^{EH} = \ln\left|1 + \frac{1}{2}\frac{Z_0}{Z_{\text{м}}}\kappa_{\text{м}} t\right| = \ln\left|1 + \frac{1}{2}Z_0 \sigma t\right|, \qquad (1.46)$$

where $Z_0 = Z_A^{EH} = \sqrt{\mu/\varepsilon} = 376{,}7$ ohm.

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It is necessary to keep in mind that the plane wave appears, cord radiation source is located from the screen on of the distances of 5-6 wavelengths.

Fig. 1.5 is shown the frequency dependence of the attenuation of the shadowing of copper and steel screens of relatively magnetic and electric fields in the spectrum from 0 to 10^4 Hz. The obtained results give the demonstrative and convincing representation of the nature of electrical and magnetic shielding and the special feature/peculiarities of steel and copper (aluminum) screens.

Screening effect of the electrostatic shields, equal to infinity, with constant (f = 0) with an increase of frequency descends as a result of the frequency dependence of wave dielectric resistance of relatively electric field $Z_A^E = 1/i\omega\varepsilon r_0$ and the nature of the shadowing of static electric field. Electrostatic shadowing consists of the closing/shorting of electric field on the surface of the metallic mass of screen and the transmission of electric

charges to the earth or housing of instrument. If we, for example, between wire a, carrying interference, and wire b, subjected to effect, place the connected with earth/ground or housing of instrument screen, then it will intercept electrical lines of force, shielding wire b from interferences (Fig. 1.6).

The necessary conditions of high effectiveness of electrostatic shadowing is the metallization of screen, i.e., its connection with the housing of instrument or the earth/ground.

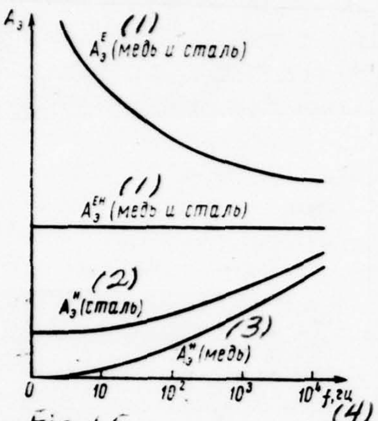

Fig. 1.5.

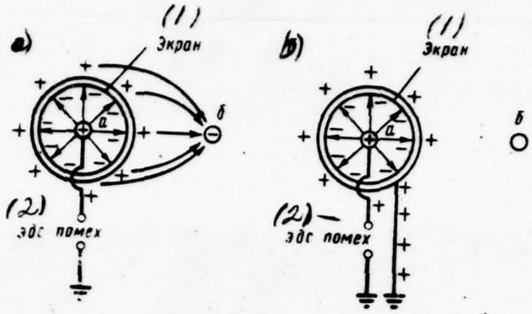

Fig. 1.6.

Fig. 1.5. Attenuation of shadowing in low-frequency range (L.F.).

Key: (1). Copper and steel. (2). steel. (3). copper. (4). Hz.

Fig. 1.6. Electrostatic shadowing: a) screen is not grounded; b) screen is grounded.

Key: (1). Screen. (2). the emf of interferences.

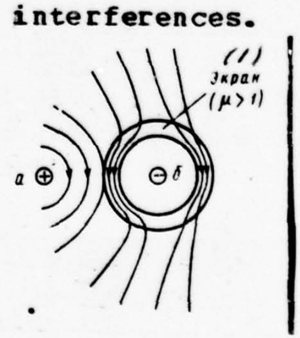

Fig. 1.7.

Fig. 1.7. Magnetostatic shadowing.

Key: (1). Screen.

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On the basis of the nature of electrostatic shadowing, it follows that the screen from any metal (copper, steel, aluminum, lead) to identical degree localizes the field of interferences and performs the role of the electrostatic shield. Moreover special requirements for the type of material, its thickness and conductivity are not presented, and therefore, as can be seen from Fig. 1.5, copper and steel screens give the identical effect of electrostatic shadowing.

Relative to magnetostatic fields steel and copper screens behave differently. This is connected with the nature of the magnetostatic shadowing, based on the closing/shorting of magnetic field in thicker than the screen, that occurs as a result of its increased magnetoconductivity. Magnetic flux (Fig. 1.7), created by the carrier of interference by wire a, is closed in thicker than magnetic screen as a result of its low reluctance and only partially it penetrates the shielded space. Therefore

for a magnetostatic screen usually is utilized steel, nickel and other materials, which possess the increased magnetic permeability. Nonmagnetic metals (copper, aluminum, lead), cannot perform the role of magnetostatic screen. As can be seen from Fig. 1.5, the effect of copper screen relative to magnetic fields in the range low frequencies is virtually negligible, and steel - is sufficiently high.

The effectiveness of magnetostatic shadowing the greater, the greater its magnetic permeability μ and is more the thickness of screen t. With an increase in the radius r_3 the effectiveness of magnetostatic screen descends. For obtaining the reliable magnetostatic shadowing of wall, they make comparatively thick or is applied compound/composite screen from several layers of metal with large magnetic permeability.

Magnetostatic screens are effective only with direct current and in the range of low frequencies. With an increase in the frequency, grow/rise the eddy currents in screen, occurs the displacement of magnetic field from the thickness of screen and its increased magnetoconductance loses its value. In the range of high frequencies magnetic (steel) screen passes from magnetostatic to the

electromagnetic mode/conditions, which operates on the principle of the onset of eddy currents in thicker than the screen. Nonmagnetic (copper) screen in all frequency band operates in electromagnetic mode/conditions; therefore its effectiveness in the range of low frequencies is very small.

The attenuation of the shadowing of plane wave (A_s^{EH}) in the frequency band in question constantly and in value is more than during the shadowing of magnetic field (A_s^{H}), and are less than during the shadowing of electric field (A_s^{E}), i.e., $A_s^H < A_s^{EH} < A_s^E$ (Fig. 1.5).

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1.6. Electromagnetic shadowing.

The electrostatic and magnetostatic screens, which operate on the principle of the closing/shorting of the corresponding fields, as a result of the increased the electro- and magnetoconductance of materials are effective only in the range of low frequencies. The action of

electromagnetic screens can be presented as multiple reflection of electromagnetic waves from the surface of screen and the attenuation of high-frequency energy in metallic thicker screen. The attenuation of energy in screen is caused by thermal eddy current losses in metal. The higher the frequency and is thicker the screen, the greater the energy absorption in screen and is more the value of screen attenuation because of absorption.

The reflection of energy is connected with the nonconformity of the wave characteristics of dielectric and metal from which is made the screen. The more differ between themselves the wave dielectric resistance and metal, the more powerful the effect of screen attenuation because of reflection. This explanation corresponds to the physical essence of the indicated process of shadowing.

As can be seen from Fig. 1.8, the electromagnetic energy W, after achieving screen, is partially passed through the screen, attenuating in it thicker, and it is partially reflected off screen W^{01} (first boundary dielectric - screen). On the second boundary (screen, dielectric,) occurs the secondary reflection of energy (W^{02}), and only the remaining part penetrates the shielded space.

Consequently, energy in transit through the screen decreases with W to $W_э$. In this example the phenomenon of reflection is represented somewhat simply. In actuality occurs the multiple reflection of energy from boundaries dielectric - screen - dielectric.

Electromagnetic shadowing can be realized with the aid of nonmagnetic and magnetic screens, but nonmagnetic (copper, aluminum) is given up preference, since they are introduced less than the loss into the circuit of transmission. In the determined frequency region the best effect give the multilayer combined screens, which consist of the consecutively alternating layers of magnetic and nonmagnetic metals.

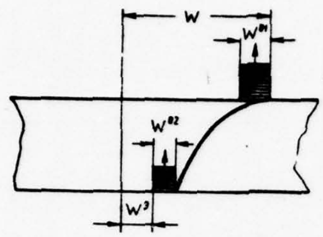

Fig. 1.8. Passage of electromagnetic energy through screen: W - field of interferences; W^{01} and W^{02} - reflected fields; $W^{э}$ is field after screen.

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Calculation of electromagnetic screens can be realized by the following formulas:

screening constant

$$S=S_{п}S_{о}=\frac{1}{\operatorname{ch}\kappa_{м}t}\cdot\frac{1}{1+\frac{1}{2}\left(\frac{Z_{д}}{Z_{м}}+\frac{Z_{м}}{Z_{д}}\right)\operatorname{th}\kappa_{м}t} \qquad (1.47)$$

or through the attenuation of the shadowing

$$A_{э}=A_{п}+A_{о}=\ln\left|\operatorname{ch}\kappa_{м}t\right|+\ln\left|1+\frac{1}{2}\left(\frac{Z_{д}}{Z_{м}}+\frac{Z_{м}}{Z_{д}}\right)\operatorname{th}\kappa_{м}t\right|,$$

where $Z_{д}$ is the wave dielectric resistance, equal for an electric field $Z_{д}^{E}=1/i\omega\varepsilon r_{э}$, for a magnetic field $Z_{д}^{H}=i\omega\mu r_{э}$ and for a plane wave $Z_{0}=\sqrt{\mu/\varepsilon}$.

The formula of the calculation of the attenuation of shadowing $(A_э)$ consists of two parts: $A_п = \ln\left|\frac{1}{S_п}\right| = \ln|\mathrm{ch}\,\kappa_м t|$ is screen attenuations of absorption and $A_o = \ln\left|\frac{1}{S_o}\right| = \ln\left|1 + \frac{1}{2}\left(\frac{Z_д}{Z_м} + \frac{Z_м}{Z_д}\right)\mathrm{th}\,\kappa_м t\right|$ - screen attenuation of reflection will be simplified

If the screen is electrically thick, i. e. its attenuation κt exceeds 1.5 Np then the second boundary of reflection $(Z_м/Z_д)$ may be disregarded and the formula for screen attenuation of reflection is simplified

$$A_o = \ln\left|1 + \frac{1}{2}\frac{Z_д}{Z_м}\mathrm{th}\,\kappa_м t\right|.$$

These formulas, obtained from the equations of Maxwell in quasi-stationary mode/conditions, are not considered bias currents and therefore are valid in the limited frequency range approximately 10^8-10^9 Hz.

The shadowing of absorption $A_п$ is caused by thermal eddy current losses in the metal of screen. The higher the frequency and is thicker the screen, the greater screening effect. The shadowing of reflection is connected with the nonconformity of the wave characteristics of the metal from which is made the screen, and the dielectric, which surrounds screen. The greater the difference between the wave dielectric resistance and metal, the more powerful screening effect of reflection.

Table 1.1 gives the results of the calculation of the screening effect of screens from different metals (copper, steel, aluminum and lead) for the different types of fields (magnetic, electrical, the plane wave). From the preceding information it is evident that value $A_\text{п}$ is identical for all transmission modes. Analyzing the formula of the shadowing of absorption $A_\text{п}$ and given data, it can be noted that screening effect grow/rises in direct dependence on the coefficient of eddy currents k and of the thickness of screen t. With an increase of frequency, value $A_\text{п}$ changes sufficiently sharply.

From the given formulas also follows that the greater magnetic permeability μ and the conductivity of screen σ, that higher screening effect. Therefore screening effect of absorption of magnetic screens is substantially more than in nonmagnetic screens. This is visually shown in Table 1.1, where is given the frequency dependence of screen attenuation for the screens of different metals in frequency spectrum to 10^9 Hz. At frequency 1 MHz, screening effect in steel into six and more times is higher than copper. From nonmagnetic metals greatest screening effect has copper, then goes aluminum and smallest effect of lead.

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With an increase in the thickness of screen, screening effect increases. The coefficient of eddy currents k and equivalent depth of penetration θ are determined by the formulas:

$$\kappa = \sqrt{i\omega\mu\sigma} = \frac{1+i}{\sqrt{2}}\sqrt{\omega\mu\sigma} = \sqrt{\frac{\omega\mu\sigma}{2}}(1+i),\ \theta = \frac{1+i}{\kappa} = \sqrt{\frac{2}{\omega\mu\sigma}}.$$

Table 1.2 gives corrected values of the module/moduli of the coefficients of vortex/eddy it is such $|\kappa = \sqrt{i\omega\mu\sigma}|$ for different metals and the results of the calculation of equivalent depth of penetration.

The screen attenuation of absorption $A_п$ does not depend on transmission mode and has identical value for electrical and magnetic fields and a plane wave. The screen attenuation of reflection (A_0) depends substantially on the form of field. This is caused by a difference in the values of the wave dielectric resistance of electrical (Z magnetic $(Z_д^H)$ and plane wave (Z_0). The screen attenuation of reflection is determined that mainly, by the nonconformity of the wave dielectric resistance $Z_д$ and of the metal $Z_м$, from which is made the screen.

Table 1.1. Screening effect of screens from the different metals of the relatively electrical magnetic and plane of waves.

f, гц (3)	(1) Медь							(2) Сталь (μ=100)						
	$A_п$	$A_о^H$	$A_о^E$	$A_о^{EH}$	$A_э^H$	$A_э^E$	$A_э^{EH}$	$A_п$	$A_о^H$	$A_о^E$	$A_о^{EH}$	$A_э^H$	$A_э^E$	$A_э^{EH}$
10^3	0	0,18	29,4	13,9	0,18	29,4	13,8	0	0	27,2	11,8	0	27,2	11,8
10^4	0	0,92	27,0	13,9	0,92	27,0	13,8	0,03	0	24,8	11,8	0,03	24,8	11,8
10^5	0,02	3,08	24,6	13,8	3,1	24,6	13,8	0,97	0,78	21,8	11,0	1,75	22,8	12,0
10^6	0,75	4,76	21,6	13,2	5,51	22,3	13,9	4,67	1,52	20,5	9,8	6,19	25,2	14,5
10^7	4,06	5,8	18,0	12,0	9,86	22,1	16,1	16,3	2,53	14,8	8.6	18,83	31,1	24,9
10^8	14,35	6,9	14,7	10,8	21,25	29,0	25,2	54,1	3,64	11,3	7,5	57,74	65,4	61,6
10^9	46,60	8,2	11,2	9,6	54,8	57,8	56,2	168,0	4,90	7,9	6,3	172,9	175,9	174,3

f, гц (3)	(4) Алюминий							(5) Свинец						
	$A_п$	$A_о^H$	$A_о^E$	$A_о^{EH}$	$A_э^H$	$A_э^E$	$A_э^{EH}$	$A_п$	$A_о^H$	$A_о^E$	$A_о^{EH}$	$A_э^H$	$A_э^E$	$A_э^{EH}$
10^3	0	0,11	28,7	13,3	0,11	28,7	13,3	0	0	26,8	11,4	0	26,8	11,4
10^4	0	0,51	26,4	13,3	0,51	26,4	13,3	0	0,18	24,4	11,3	0,18	24,4	11,3
10^5	0,002	2,78	24,1	13,3	2,8	24,1	13,3	0	0,71	22,1	11,3	0,71	22,1	11,3
10^6	0,39	4,81	21,8	13,2	5,2	22,2	13,6	0,01	2,88	19,8	11,3	2,89	19,8	11,3
10^7	2,97	5,47	17,7	11,6	8,44	20,7	14,6	0,58	4,66	17,0	10,8	5,24	17,6	11,4
10^8	10,9	6,70	14,4	10,5	17,6	25,3	21,4	3,54	5,8	13,4	9,6	9,34	16,9	13,1
10^9	35,9	7,90	11,0	9,4	43,8	46,9	45,3	12,65	6,9	9,95	8,4	19,55	22,6	21,0

Key: (1). Copper. (2). Steel. (3). Hz. (4). Aluminum. (5). Lead.

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Table 1.2. Module/modulus of the coefficient of eddy currents $|\kappa=\sqrt{i\omega\mu\sigma}|$ and the depth of penetration of high-frequency field into the thickness of screen $\theta=\sqrt{\frac{2}{\omega\mu\sigma}}$ for different metals.

f, гц (5)	(1) Медь		(2) Сталь		(3) Алюминий		(4) Свинец	
	$\kappa, \frac{1}{мм}$	$\theta, мм$	$\kappa, \frac{1}{мм}$	$\theta, мм$	$\kappa, \frac{1}{мм}$	$\theta, мм$	$\kappa, \frac{1}{мм}$	$\theta, мм$
10^4	2,121	0,667	7,561	0,187	1,635	0,864	0,597	2,357
$6\cdot10^4$	5,196	0,272	18,52	0,076	4,006	0,353	1,453	0,966
10^5	6,709	0,211	23,92	0,059	5,172	0,274	1,889	0,474
$2\cdot10^5$	9,487	0,149	33,82	0,042	7,315	0,193	2,671	0,529
$5\cdot10^5$	15,0	0,094	53,47	0,026	11,56	0,122	4,224	0,334
10^6	21,21	0,067	75,61	0,019	16,35	0,086	5,972	0,237
10^7	67,09	0,021	239,2	0,006	51,72	0,027	18,89	0,075
10^8	212,1	0,0067	756,1	0,0019	163,5	0,0086	59,72	0,0237
(6) Расчетная формула	$21,2\cdot10^{-3}\sqrt{f}$	$66,68\frac{1}{\sqrt{f}}$	75.6 $5,6\cdot10^{-3}\sqrt{f}$	$18,7\frac{1}{\sqrt{f}}$	$16,35\cdot10^{-3}\sqrt{f}$	$86,44\frac{1}{\sqrt{f}}$	$5,9\cdot10^{-3}\sqrt{f}$	$236,7\frac{1}{\sqrt{f}}$

Key: (1). Copper. (2). Steel. (3). Aluminum. (4). Lead. (5). Hz. (6). Calculation formula.

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Tables 1.3. Wave impedance (on module/modulus in ohm) for different metals.

(1) f, гц	(2) Медь	(3) Сталь	(4) Алюминий	(5) Свинец
10^3	$0,0118 \cdot 10^{-3}$	$0,3303 \cdot 10^{-3}$	$0,0153 \cdot 10^{-3}$	$0,0418 \cdot 10^{-3}$
10^4	$0,0372 \cdot 10^{-3}$	$1,044 \cdot 10^{-3}$	$0,0483 \cdot 10^{-3}$	$0,1322 \cdot 10^{-3}$
10^5	$0,118 \cdot 10^{-3}$	$3,303 \cdot 10^{-3}$	$0,153 \cdot 10^{-3}$	$0,418 \cdot 10^{-3}$
10^6	$0,372 \cdot 10^{-3}$	$10,44 \cdot 10^{-3}$	$0,483 \cdot 10^{-3}$	$1,322 \cdot 10^{-3}$
10^7	$1,18 \cdot 10^{-3}$	$33,03 \cdot 10^{-3}$	$1,53 \cdot 10^{-3}$	$4,18 \cdot 10^{-3}$
10^8	$3,72 \cdot 10^{-3}$	$104,43 \cdot 10^{-3}$	$4,826 \cdot 10^{-3}$	$13,22 \cdot 10^{-3}$
10^9	$11,8 \cdot 10^{-3}$	$330,3 \cdot 10^{-3}$	$15,3 \cdot 10^{-3}$	$41,8 \cdot 10^{-3}$
10^{10}	$37,2 \cdot 10^{-3}$	$1044,3 \cdot 10^{-3}$	$48,26 \cdot 10^{-3}$	$132,2 \cdot 10^{-3}$
10^{11}	$118 \cdot 10^{-3}$	$3303 \cdot 10^{-3}$	$153 \cdot 10^{-3}$	$418 \cdot 10^{-3}$
10^{12}	$372 \cdot 10^{-3}$	$10443 \cdot 10^{-3}$	$482,6 \cdot 10^{-3}$	$1322 \cdot 10^{-3}$
(6) Расчетная формула	$0,372 \cdot 10^{-6}\sqrt{f}$	$10,44 \cdot 10^{-6}\sqrt{f}$	$0,483 \cdot 10^{-6}\sqrt{f}$	$1,32 \cdot 10^{-6}\sqrt{f}$

Key: (1). Hz. (2). Copper. (3). Steel. (4). Aluminum. (5). Lead. (6). Calculation formula.

Tables 1.4. Wave impedance (on module/modulus in ohm) of dielectrid (air) relative to the electrical $(Z^E_Д)$, magnetic $(Z^H_Д)$ and plane (Z_0) of waves.

(3) f, гц	(1) Магнитная волна $r_э=0.001$ м	$r_э=0,01$ м	$r_э=0,1$ м	$r_э=1$ м	(2) Электрическая волна $r_э=0,001$ м	$r_э=0,01$ м	$r_э=0,1$ м	$r_э=1$ м	(4) Плоская волна
10^1	$79\cdot10^{-9}$	$79\cdot10^{-8}$	$79\cdot10^{-7}$	$79\cdot10^{-6}$	$18\cdot10^{11}$	$18\cdot10^{10}$	$18\cdot10^{9}$	$18\cdot10^{8}$	376,7
10^2	$79\cdot10^{-8}$	$79\cdot10^{-7}$	$79\cdot10^{-6}$	$79\cdot10^{-5}$	$18\cdot10^{10}$	$18\cdot10^{9}$	$18\cdot10^{8}$	$18\cdot10^{7}$	376,7
10^3	$79\cdot10^{-7}$	$79\cdot10^{-6}$	$79\cdot10^{-5}$	$79\cdot10^{-4}$	$18\cdot10^{9}$	$18\cdot10^{8}$	$18\cdot10^{7}$	$18\cdot10^{6}$	376,7
10^4	$79\cdot10^{-6}$	$79\cdot10^{-5}$	$79\cdot10^{-4}$	$79\cdot10^{-3}$	$18\cdot10^{8}$	$18\cdot10^{7}$	$18\cdot10^{6}$	$18\cdot10^{5}$	376,7
10^5	$79\cdot10^{-5}$	$79\cdot10^{-4}$	$79\cdot10^{-3}$	$79\cdot10^{-2}$	$18\cdot10^{7}$	$18\cdot10^{6}$	$18\cdot10^{5}$	$18\cdot10^{4}$	376,7
10^6	$79\cdot10^{-4}$	$79\cdot10^{-3}$	$79\cdot10^{-2}$	$79\cdot10^{-1}$	$18\cdot10^{6}$	$18\cdot10^{5}$	$18\cdot10^{4}$	$18\cdot10^{3}$	376,7
10^7	$79\cdot10^{-3}$	$79\cdot10^{-2}$	$79\cdot10^{-1}$	79	$18\cdot10^{5}$	$18\cdot10^{4}$	$18\cdot10^{3}$	$18\cdot10^{2}$	376,7
10^8	$79\cdot10^{-2}$	$79\cdot10^{-1}$	79	$79\cdot10^{1}$	$18\cdot10^{4}$	$18\cdot10^{3}$	$18\cdot10^{2}$	$18\cdot10^{1}$	376,7
10^9	$79\cdot10^{-1}$	79	$79\cdot10^{1}$	$79\cdot10^{2}$	$18\cdot10^{3}$	$18\cdot10^{2}$	$18\cdot10^{1}$	18	376,7
(5) Расчетная формула	$Z^H_Д = i\omega\mu r_э = i79\cdot10^{-7} f r_э$				$Z^E_Д = \frac{1}{i\omega\varepsilon r_э} = \frac{18\cdot10^9}{if\varepsilon r_э}$				$Z_0 = \frac{120\pi}{\sqrt{\varepsilon}}$

Note ε - relative dielectric permeability (for air $\varepsilon = 1$); $r_э$, м; f, Hz.

Key: (1). Magnetic wave. (2). Electrical wave. (3). Hz. (4). Plane wave. (5). Calculation formula.

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The more differ between themselves values $Z_Д$ and $Z_М$, the greater the value of the reflections of energy on boundaries dielectric - screen - dielectric.

The values of the wave impedance of different metals

(copper, steel, aluminum, lead) are given in Table 1.3, and dielectric (air) relative to the electrical, magnetic and plane of waves - in Table 1.4. Relationship/ratios $Z_д/Z_м$ for different metals with f = 10^6 Hz and $r_э=0{,}01$ are given in Table 1.5 (see Fig. 1.3).

In the considered frequency region (tc 10^9 Hz) $Z_д^E>Z_д^H$ and the relationship/ratio $Z_д^E/Z_м>Z_д^H/Z_м$, i.e., boundary dielectric - the metal of relatively electrical wave gives substantially larger effect than relative to magnetic wave. Comparing different metals it should be noted that the best effect of reflection of copper, then goes aluminum, lead and the smallest reflectivity of steel. Therefore copper, substantially being inferior steels on the attenuation of absorption $(A_п)$, it has very great advantages on the attenuation of reflection (A_0).

Tables 1.6 and 1.7 and Fig. 1.9 gives corrected values of the screen attenuation of the reflection of copper screen for different frequencies and radii of screen. Here for a comparison is given the curve/graph of the attenuation of absorption $A_п$.

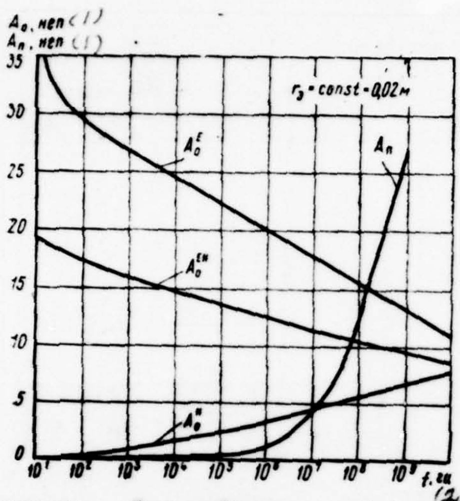

Fig. 1.9. Frequency dependence of attenuation of absorption ($A_п$) and of reflections of magnetic wave (A_0^H), of electrical wave (A_0^E) and of plane wave (A_0^{EH})

Key: (1). Np. (2). Hz.

Table 1.5. Relationship/ratio $Z_Э/Z_М$ for different metals with f = 10^6 Hz and $r_э$=0,01 mm.

(1) Вид волны	(2) Медь	(3) Сталь	(4) Алюминий	(5) Свинец
Электрическая (6)	$48,6 \cdot 10^8$	$1,7 \cdot 10^8$	$37,5 \cdot 10^8$	$13,7 \cdot 10^8$
Магнитная (7)	215	7,6	164	60
Плоская (8)	1013	36,1	781	285

Key: (1). Form of wave. (2). Copper. (3). Steel. (4). Aluminum. (5). Lead. (6). Electrical. (7). Magnetic. (8). Flat/plane.

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Table 1.6. Frequency dependence of the attenuation of the reflection of the copper screen of the different tones of wave (with $r_э=0,02$ mm).

f, гц	$Z^E_{Д}$, ом	$Z^H_{Д}$, ом	Z_0, ом	$Z_м$, ом	$\frac{Z^E_Д}{Z_м}$	$\frac{Z^H_Д}{Z_м}$	$\frac{Z_0}{Z_м}$	A^E_0, неп	A^H_0, неп	A^{EH}_0, неп
10^1	$9\cdot10^{10}$	$157,7\cdot10^{-8}$	376,7	$0,0118\cdot10^{-4}$	$7,54\cdot10^{16}$	$317,0\cdot10^{6}$	$101,2\cdot10^{7}$	31,698	—1,04	19,326
10^2	$9\cdot10^{9}$	$157,7\cdot10^{-7}$	376,7	$0,0372\cdot10^{-4}$	$2,419\cdot10^{15}$	4,239	$101,2\cdot10^{6}$	29,396	0,412	17,026
10^4	$9\cdot10^{7}$	$157,7\cdot10^{-5}$	376,7	$0,0372\cdot10^{-3}$	$2,419\cdot10^{12}$	$4,239\cdot10^{1}$	$101,2\cdot10^{5}$	24,796	2,54	14,726
10^6	$9\cdot10^{5}$	$157,7\cdot10^{-3}$	376,7	$0,0372\cdot10^{-2}$	$2,419\cdot10^{9}$	$4,239\cdot10^{2}$	$101,2\cdot10^{4}$	20,196	4,59	12,426
10^8	$9\cdot10^{3}$	$157,7\cdot10^{-1}$	376,7	$0,0372\cdot10^{-1}$	$2,419\cdot10^{6}$	$4,239\cdot10^{3}$	$101,2\cdot10^{3}$	15,596	6,89	10,126
10^{10}	$9\cdot10^{1}$	$157,7\cdot10^{1}$	376,7	0,0372	$2,419\cdot10^{3}$	$4,239\cdot10^{4}$	$101,2\cdot10^{2}$	10,996	9,19	7,826

[гц = Hz; ом = Ω; неп = Np]

Table 1.7. Dependence of the attenuation of the reflection of copper screen with different radii of screen (with f = 10^6 Hz.).

$r_э$, м	$Z^E_{Д}$, ом	$Z^H_{Д}$, ом	Z_0, ом	$Z_м$, ом	$\frac{Z^E_Д}{Z_м}$	$\frac{Z^H_Д}{Z_м}$	$\frac{Z_0}{Z_м}$	A^E_0, неп	A^H_0, неп	A^{EH}_0, неп
$2\cdot10^{-2}$	$9\cdot10^{5}$	$157,7\cdot10^{-3}$	376,7	$0,0372\cdot10^{-2}$	$2,419\cdot10^{9}$	$4,239\cdot10^{2}$	$101,2\cdot10^{4}$	20,196	4,59	21,626
$2\cdot10^{-1}$	$9\cdot10^{4}$	$157,7\cdot10^{-2}$	376,7	$0,0372\cdot10^{-2}$	$2,419\cdot10^{8}$	$4,239\cdot10^{3}$	$101,2\cdot10^{4}$	17,896	6,89	21,626
2	$9\cdot10^{3}$	$157,7\cdot10^{-1}$	376,7	$0,0372\cdot10^{-2}$	$2,419\cdot10^{7}$	$4,239\cdot10^{4}$	$101,2\cdot10^{4}$	15,596	9,19	21,626
$2\cdot10^{1}$	$9\cdot10^{2}$	157,7	376,7	$0,0372\cdot10^{-2}$	$2,419\cdot10^{6}$	$4,239\cdot10^{5}$	$101,2\cdot10^{4}$	13,296	11,49	21,626
$2\cdot10^{2}$	$9\cdot10^{1}$	$157,7\cdot10^{1}$	376,7	$0,0372\cdot10^{-2}$	$2,419\cdot10^{5}$	$4,239\cdot10^{6}$	$101,2\cdot10^{4}$	10,996	13,79	21,626

[ом = Ω; неп = Np]

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From the preceding information it is evident that the attenuation of the reflection of electric field A_o^E, having very large values in the range of low frequencies, with an increase of frequency sharply it decreases. The attenuation of the reflection of magnetic field A_o^H, on the contrary, on frequency curve/graph has the growing character, increasing from zero when f = 0, moreover $A_o^E > A_o^H$. With an increase in the radius of screen A_o^H it grow/rises, and A_o^E decreases.

Let us examine the resulting effectiveness $(A_э = A_п + A_о)$ the screens of relatively electrical and magnetic fields. Figures 1.10 and Table 1.1 gives calculated data of the attenuations of the shadowing of the copper screen with a thickness of 0.1 mm in the range of frequencies to 10^9 Hz. The attenuation of the shadowing of magnetic field $A_э^H$ has in all frequency band the growing character. Decay curve of the shadowing of electrical field $A_э^E$ has complex nature - first it falls, and then it increases. The minimum is observed at frequencies 10^6-10^7 Hz. The attenuation of shadowing as the strip of wave in the range

to 10^6-10^7 Hz has constant value, and then grow/rises because of absorption in metal. Rate/estimating the specific significance of the components of shadowing $A_п$ (absorption) and A_0 (reflection), it can be noted that in the range approximately to 10^7 Hz prevails the attenuation of reflection, but above becomes determining the attenuation of absorption. The role of the attenuation of absorption is especially great of magnetic screens.

As a whole, comparing screening effect of uniform screens with different transmission modes (Table 1.1), it is possible to state/establish that the electric field is shielded substantially better than magnetic, i.e., $A_э^E > A_э^H$. Plane wave is the intermediate position that ($A_э^E > A_э^{EH} > A_э^H$).

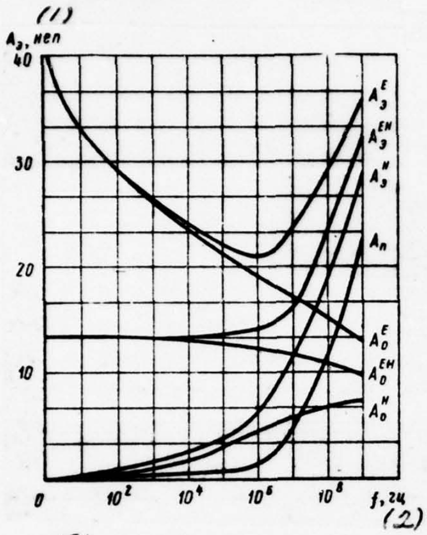

Fig. 1.10

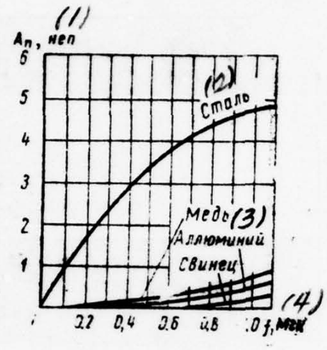

Fig. 1.11

Fig. 1.10. Comparative effectiveness of electrical and magnetic shielding.

Key: (1). Np. (2). Hz.

Fig. 1.11. Attenuation of absorption of screens from different metals.

Key: (1). Np. (2). Steel. (3). Copper, aluminum, lead. (4). MHz.

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Therefore magnetic fields are definite during screens and from their mixing effect necessary first of all to shield couplers and radio mechanics.

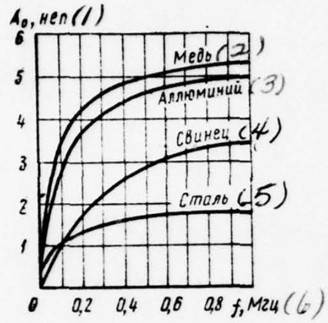
Let us examine in more detail the effectiveness of screens of relatively magnetic fields.

Figures 1.11, 1.12 and 1.13 give corrected values $A_п, A_о, A_э$ for magnetic screens from copper, aluminum, lead they will stop thickness of 0.1 mm. Maximum value possesses steel screen (see also Table 1.1). Maximum value $A_п$ for nonmagnetic screens possesses copper, then goes aluminum and finally lead ($A_п$ for lead 100 times less than for copper). This is explained by the poor conductivity σ of lead. The screen attenuation of reflection A_0 at frequency only 1 Np, aluminum - 3.4 Np, but stopped in all only 1 Np, i.e., nonmagnetic screens have the high value A_0.

Analyzing the screen attenuation of different screens as a whole ($A_э = A_п + A_о$), it can be noted that in frequency range approximately to 10^6 Hz the greatest result give the copper and aluminum screens, and in higher frequency spectrum the

advantage remains after steel screens. However, in a number of cases due to high electrical losses, steel becomes unsuitable for the production of single-layer screens. With an increase μ of steel, occurs the redistribution of the screen attenuation of absorption and screen attenuation of reflection. Change μ from 100 to 200 gives an increase A_m approximately on 0.8 Np, and value A_0 decreases. As a whole the increase μ gives substantially positive effect in an increase in the screen attenuation.

Figures 1.14 shows the dependence of the screen attenuation of copper and steel screens on thickness.



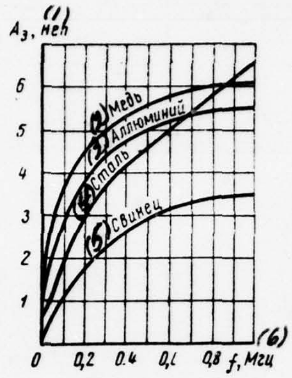


Fig. 1.12.

Fig. 1.13

Fig. 1.12. Attenuation of reflection of screens from different metals.

Key: (1). Np. (2). Copper. (3). Aluminum. (4). Lead. (5). Steel. (6). MHz.

Fig. 1.13. Resulting of attenuation of shadowing of different metals.

Key: (1). Np. (2). Copper. (3). Aluminum. (4). Steel. (5). Lead. (6). MHz.

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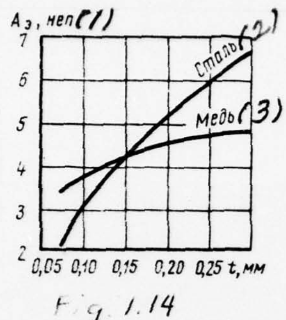
With an increase in the thickness of screen, increases it that screens, moreover the character of this growth of magnetic and nonmagnetic materials is various. $A_{э}$ honeys comparatively temporarily increases with an increase in the thickness of screen. Increase t in steel is led to a sharp increase in screening effect. So, during a change in the thickness of screen from 0.1 to 0.2 mm screen attenuation grow/rises at copper by 20o.o, and of steel - to 70o/o. This is explained to the facts that in the frequency spectrum being investigated of magnetic materials considerable role plays the component of the screen attenuation of absorption $A_{п}$; of nonmagnetic materials this component is very small.

The conductivity of metal substantially affects the shielding properties of screen (Fig. 1.15). Screening effect of the nonmagnetic screens of equal thickness is caused by the properties of electrical conductivity of metals. The sequence of metals on the shielding effect (copper - aluminum - lead) corresponds to the sequence of their conductivities σ. As a result of the fact that σ lead is 13 times less σ copper, screening effect of the lead shield is 2-2.5 times less than copper one.

1.7. Wave mode/conditions of shadowing.

The wave mode/conditions of shadowing is propagated in the range of the superhigh frequencies: from $10^{9}-10^{10}$ Hz it is above, encompassing the range of decimeter, centimeter and millimeter waves. The limit of the demarcation of electromagnetic and wave mode/conditions is the commensurability of wavelength λ with the diameter of screen $D_{э}$: when $\lambda \leqslant D_{э}$ sets in the wave mode/conditions of shadowing. In this case one should proceed from the complete equations of electrodynamics and along with conduction currents to consider bias currents.



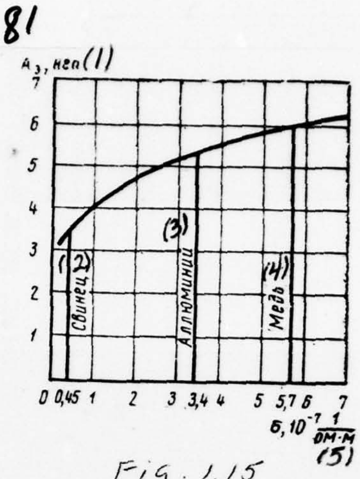


Fig. 1.14. Dependence of attenuation of shadowing on thickness of screen.

Key: (1). Np. (2). Steel. (3). Copper.

Fig. 1.15. Dependence of attenuation of shadowing on conductivity of metal.

Key: (1). Np. (2). Lead. (3). Aluminum. (4). Copper. (5) $1/\Omega \cdot m$.

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If in the examination of electromagnetic screens it was subject to operate with fundamental wave of electric wave mode, then in wave mode/conditions one should proceed from

the waves of higher order TE and TM.

The special feature/peculiarity of wave mode/conditions is fluctuating wavelike nature of a change in the attenuation of the shadowing of electrical and magnetic wave with an increase of frequency. This is connected both with the nature of electromagnetic field of superhigh frequencies and with the special feature/peculiarities of mathematical apparatus for the calculation of screens. For a plane wave the attenuation of shadowing $A_{\circ}^{EH}$ in all frequency range from 0 to SHF smoothly grow/rises without any oscillatory phenomena.

Table 1.8. Value of wave dielectric resistance in electrical $Z_д^E$ and magnetic $Z_д^H$ fields.

f, гц (1)	$\kappa_д r_э$	$Z_д^E$	$Z_д^H$
10^3	$2{,}096\cdot10^{-7}$	$1{,}8\cdot10^{9}$	$7{,}9\cdot10^{-5}$
10^4	$2{,}096\cdot10^{-6}$	$1{,}8\cdot10^{8}$	$7{,}9\cdot10^{-4}$
10^5	$2{,}096\cdot10^{-5}$	$1{,}8\cdot10^{7}$	$7{,}9\cdot10^{-3}$
10^6	$2{,}096\cdot10^{-4}$	$1{,}8\cdot10^{6}$	$7{,}9\cdot10^{-2}$
10^7	$2{,}096\cdot10^{-3}$	$1{,}8\cdot10^{5}$	$7{,}9\cdot10^{-1}$
10^8	$2{,}096\cdot10^{-2}$	$1{,}8\cdot10^{4}$	7,9
10^9	$2{,}096\cdot10^{-1}$	1760	87
$4{,}24\cdot10^9$	0,89	106,0	410
$5{,}42\cdot10^9$	1,14	0	536
$7{,}15\cdot10^9$	1,5	15,8	686
$8{,}77\cdot10^9$	1,84	0	780
10^{10}	2,096	69,5	820
$1{,}04\cdot10^{10}$	2,19	101	810
$1{,}15\cdot10^{10}$	2,19	101	810
$1{,}15\cdot10^{10}$	2,41	176	778
$1{,}82\cdot10^{10}$	3,84	545	0
$2{,}54\cdot10^{10}$	5,33	0	760
$3{,}33\cdot10^{10}$	7,0	643	0
$4{,}08\cdot10^{10}$	8,56	0	756
$4{,}85\cdot10^{10}$	10,2	680	0
$5{,}58\cdot10^{10}$	11,7	0	755
$6{,}35\cdot10^{10}$	13,34	695	0
$7{,}08\cdot10^{10}$	14,86	0	754
$7{,}86\cdot10^{10}$	16,5	704	0
$8{,}58\cdot10^{10}$	18,0	0	749
$9{,}34\cdot10^{10}$	19,6	715	0
10^{11}	20,96	109	740

Key: (1). Hz.

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During the calculation of screens in the wave mode/conditions of relatively electrical and magnetic fields, one should use known already formula $A_э=A_п+A_о=\ln|\mathrm{ch}\,\kappa_м t|+\ln\left|1+\frac{1}{2}\frac{Z_д}{Z_м}\mathrm{th}\,\kappa_м t\right|$ where all the values, except wave dielectric resistance $Z_д$,

are identical for electrical and magnetic fields. For magnetic and electric fields wave impedance respectively

$$\left.\begin{aligned} Z_{\text{д}}^{H} &= Z_0 \, i \pi \kappa_{\text{д}} r_{\text{э}} J_1(\kappa_{\text{д}} r_{\text{э}}) H_1(\kappa_{\text{д}} r_{\text{э}}) \\ Z_{\text{д}}^{E} &= Z_0 \, i \pi \kappa_{\text{д}} r_{\text{э}} J_1'(\kappa_{\text{д}} r_{\text{э}}) H_1'(\kappa_{\text{д}} r_{\text{э}}) \end{aligned}\right\}. \qquad (1.48)$$

The screen attenuation of absorption $A_{\text{п}} = \ln|\operatorname{ch} \kappa_{\text{м}} t|$ for electrical and magnetic fields is equal. The screen attenuation of reflection A_0 because of values $Z_{\text{д}}^{E}$ and $Z_{\text{д}}^{H}$ for electrical and magnetic fields is different.

Table 1.8 and Fig. 1.3 gives corrected values of wave dielectric resistance of the relatively electrical $Z_{\text{д}}^{E}$ and magnetic $Z_{\text{д}}^{H}$ of waves. Approximately to equality between the wavelength and the diameter of screen $(\lambda \approx D_{\text{э}})$ the curve/graphs of wave dielectric resistance $Z_{\text{д}}^{E}$ and $Z_{\text{д}}^{H}$ have smooth character, and then in range SHF, beginning with 10^9 Hz they bear the oscillatory nature: for a wave $Z_{\text{д}}^{E}$ - increasing, and for $Z_{\text{д}}^{H}$ - damping. These wave processes occur closely value $Z_0 = \sqrt{\frac{\mu}{\varepsilon}}$.

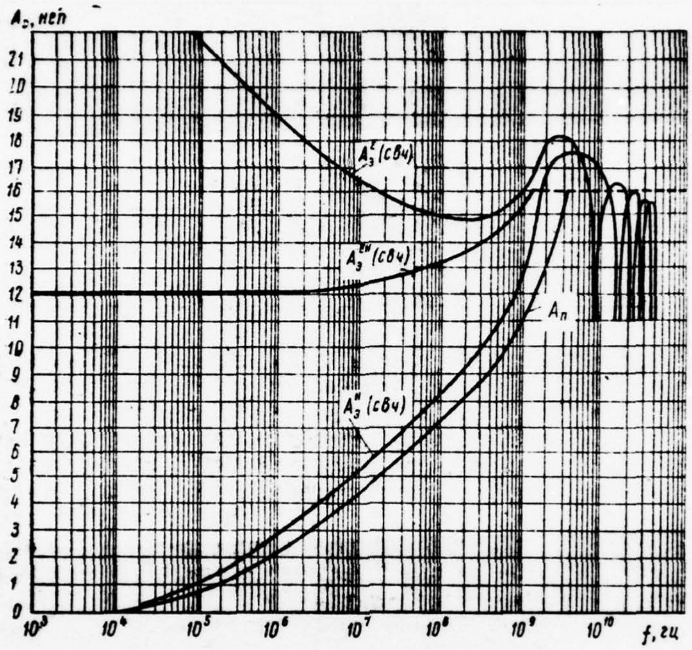

Fig. 1.16. Frequency dependence of attenuation of shadowing of electrical $A_э^E$ and magnetic $A_э^H$ of fields, plane wave $A_э^{EH}$ and attenuation of absorption $A_п$ in the range of SHF.

[Неп = Np; сВч = SHF; гц = Hz]

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Table 1.9 and Fig. 1.16 shows the values of the attenuation of the shadowing of the electrical $A_э^E$ and magnetic $A_э^H$ SHF fields in wave zone. In figure is also

given the frequency dependence of the attenuation of absorption $A_{п}$. During graphing of the value of the attenuation of shadowing, they are limited to value 17 Np, since large values difficult to measure and to realize. The attenuation of absorption for both fields equally has smoothly increasing character. The attenuation of shadowing $A_э$ and the attenuation of reflection A_0 have an oscillatory nature. Physically this phenomenon connected with resonance phenomena when $\lambda \leqslant D_э$ testifies to the wave nature of electromagnetic field on SHF. Mathematically this is caused by the presence in the formulas of calculation $A_э$ (SHF) the cylindrical functions of the first (I_1) and third (H_1) kinds that are given to attenuation an oscillatory nature. In the points, which correspond to the zero coordinates of function I_1, failures reach $-\infty$. For a magnetic wave the resonance begins when $\kappa_{\text{н}} r_э = 3{,}83;\ 7{,}015;\ 10{,}167$ so forth. Or, bearing in mind that $\kappa_{\text{н}} r_э = \omega \sqrt{\mu\varepsilon}\, r_э = 2\pi f \frac{r_э}{c} = \pi D_э \frac{f}{c} = \frac{\pi D_э}{\lambda}$ we will obtain the points of resonance with following relationship/ratios $D_э/\lambda = 1{,}22;$ 2.234; 3.238; etc.

Table 1.9. Values of the attenuation of the shadowing of the electrical $A_э^E$ and magnetic $A_э^H$ of fields in wave zone with different radii of screen.

$r_э$=1,5мм; t=0,01мм			$r_э$=15мм; t=0,01мм		
f, гц (1)	$A_э^H$	$A_э^E$	f, гц	$A_э^H$	$A_э^E$
10^8	9,55	17,60	10^8	10,20	19,10
$6,37\cdot10^8$	13,74	15,41	$6,37\cdot10^9$	16,09	17,77
$1,26\cdot10^9$	16,36	16,55	$1,26\cdot10^{10}$	16,20	16,40
$2,53\cdot10^9$	16,18	14,44	$1,67\cdot10^{10}$	19,21	15,82
$2,93\cdot10^9$	—	∞	$2,53\cdot10^{10}$	16,18	14,44
$3,31\cdot10^9$	16,03	14,28	$2,93\cdot10^{10}$	—	∞
$5,67\cdot10^9$	14,12	15,41	$3,31\cdot10^{10}$	16,03	14,28
$6,1\cdot10^9$	∞	—	$3,57\cdot10^{10}$	15,95	14,67
$6,3\cdot10^9$	13,24	15,27	$4,1\cdot10^{10}$	15,69	15,15
$8,2\cdot10^9$	14.05	13,30	$5,67\cdot10^{10}$	14,12	15,41
$8,49\cdot10^9$	—	∞	$6,1\cdot10^{10}$	∞	—
$8,75\cdot10^9$	14,99	13,07	$6,3\cdot10^{10}$	13,24	15,27
$1,07\cdot10^{10}$	13,48	14,76	$8,2\cdot10^{10}$	14,05	13,30
$1,12\cdot10^{10}$	∞	—	$8,49\cdot10^{10}$	—	∞
$1,29\cdot10^{10}$	14,49	13,73	$8,75\cdot10^{10}$	14,99	13,07
$1,36\cdot10^{10}$	—	∞	$1,07\cdot10^{11}$	13,43	14,76
$1,45\cdot10^{10}$	14,35	13,86	$1,12\cdot10^{11}$	∞	—
$1,55\cdot10^{10}$	13,52	14,35	$1,29\cdot10^{11}$	14,49	13,73
$1,62\cdot10^{10}$	∞	—			
$1,70\cdot10^{10}$	13,60	14,08			

Key: (1). Hz.

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For an electrical wave the resonance begins when $\kappa_{п} r_{э}=1,84;\ 5,33;\ 8,53$ so forth, which corresponds to relationship/ratios $D_э/\lambda=0,58;\ 1,70;\ 2,72$ so forth.

As can be seen from Table 1.9, in the range of frequencies 10^9-10^{11} Hz, there is on 2-3 resonances for

magnetic and electric waves. Thus, resonance phenomena are observed for both transmission modes: magnetic and electrical with the difference only in amplitude and frequencies of resonance. Mathematically its difference between A_s^H and A_s^E is caused by the facts that in the first case in formula figure as functions I_1 and H_1, and in the second derivative of these functions I'_1 and H'_1. With f = 0, product I_1H_1 gives zero and therefore for a magnetic field with f = 0 $A_s^H=0$, but the product of the derived these functions $I'_1H'_1$ gives infinity and therefore for an electrical field at f = 0 value $A_s^E=\infty$. For a plane wave the attenuation of shadowing A_s^{EH} in all frequency range from 0 to SHF smoothly they grow/rise without oscillatory phenomena.

Is of interest to compare the formulas of the calculation of the attenuation of shadowing in electromagnetic (h.f.) and wave (SHF) mode/conditions. Since the attenuation of absorption A_π in both cases is equal, let us examine only the formulas of the attenuation of reflection A_0.

For the magnetic field:

$$A_o^H(\text{вч}) = \ln\left|1 + \frac{1}{2}\cdot\frac{Z_д^H}{Z_м}\,\text{th}\,\kappa_м t\right|,$$

$$A_o^H(\text{свч}) = \ln\left|1 + \frac{1}{2}\frac{Z_0}{Z_м}\,i\,\pi\,\kappa_д r_э J_1(\kappa_д r_э)\,H_1(\kappa_д r_э)\,\text{th}\,\kappa_м t\right|,$$

[ВЧ = h.f; СВЧ = SHF]

where $Z_д^H = i\omega\mu r_э$. Bearing in mind that $Z_0 i\kappa_д r_э = \sqrt{\frac{\mu}{\varepsilon}}\,i\,\omega\sqrt{\mu\varepsilon}\,r_э = i\,\omega\mu r_э = Z_д^H$ we will obtain that A_o^H (SHF) $= \ln\left|1 + \frac{1}{2}\frac{Z_д^H}{Z_м}\pi J_1(\kappa_д r_э)\,H_1(\kappa_д r_э)\,\text{th}\,\kappa_м t\right|$. Disregarding by one as compared with the second member of sum, we can record A_o^H (SHF) $= A_o^H$ (h.f.) $+\Delta A_o^H$, where $\Delta A_o^H = \ln|\pi J_1(\kappa_д r_э) H_1(\kappa_д r_э)|$ or

$$A_o^H(\text{свч}) = A_o^H(\text{вч}) + \ln|\pi J_1(\kappa_д r_э)\,H_1(\kappa_д r_э)|. \quad (1.49)$$

[СВЧ = SHF; ВЧ = h.f.]

For the electric field:

$$A_o^E(\text{вч}) = \ln\left|1 + \frac{1}{2}\frac{Z_д^E}{Z_м}\,\text{th}\,\kappa_м t\right|,$$

$$A_o^E(\text{свч}) = \ln\left|1 + \frac{1}{2}\frac{Z_0}{Z_м}\,i\,\pi\,\kappa_д r_э J_1'(\kappa_д r_э)\,H_1'(\kappa_д r_э)\,\text{th}\,\kappa_м t\right|,$$

[ВЧ = h.f; СВЧ = SHF]

where $Z_д^E = \frac{1}{i\omega\varepsilon r_э}$.

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Bearing in mind that $Z_0\frac{1}{i\kappa_д r_э} = \sqrt{\frac{\mu}{\varepsilon}}\frac{1}{i\,\omega\sqrt{\mu\varepsilon}\,r_э} = \frac{1}{i\omega\varepsilon r_э} = Z_д^E$, we will obtain that A_o^E (SHF) $= \ln\left|1 + \frac{1}{2}\frac{Z_д^E}{Z_м}\pi(i\kappa_д r_э)^2 J_1'(\kappa_д r_э)\,H_1(\kappa_д r_э)\,\text{th}\,\kappa_м t\right|$. Disregarding one in comparison with the second term of sum,

we will obtain that A_0^E (SHF) $=A_0^E$ (h.f.) $+\Delta A^E$, where $\Delta A^E=\ln|\pi(i\kappa_д r_э)^2 J_1'(\kappa_д r_э)H_1'(\kappa_д r_э)|$, or $A_0^E(\text{свч}) = A_0^E(\text{вч}) + \ln|\pi(i\kappa_д r_э)^2 J_1'(\kappa_д r_э) H_1'(\kappa_д r_э)|$. (1.50)

Key: (1). SHF. (2). h.f.

Values ΔA_0^H and ΔA_0^E are caused by the special feature/peculiarities of shadowing at SHF, that characterizes wave nature of processes in this frequency domain. Figures 1.17 and 1.18 shows comparative the data of the attenuations of reflection for an electromagnetic zone (h.f.) and a wave zone (SHF), separately for the magnetic A_0^H and electrical A_0^E of waves. Figures 1.19 shows the specific significance of the resonance components ΔA_0^H and ΔA_0^E and the resulting values of the attenuation of shadowing A_0^H (SHF) and A_0^E (SHF) in wave zone.

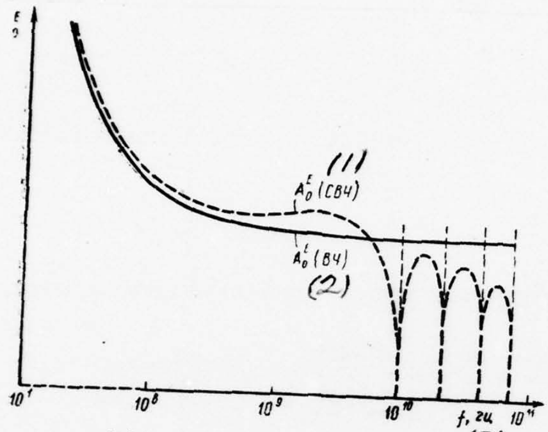

Fig. 1.17

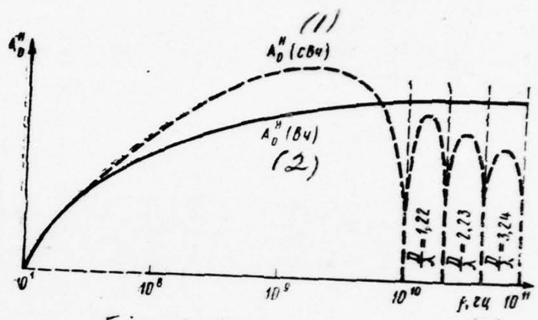

Fig. 1.18.

Fig. 1.17. Attenuation of reflection of electric field in the range of SHF.

Key: (1). SHF. (2). h.f. (3). Hz.

Fig. 1.18. Attenuation of reflection of magnetic field in the range of SHF.

Key: (1). SHF. (2). h.f. (3). Hz.

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Table 1,10 gives calculated the data of the attenuations of the shadowing of copper screen in the range of frequencies

from 10^2 to 10^{10} Hz. From curve/graphs and table, it is evident that to 10^9-10^{10} Hz of attenuation length of reflection for an electromagnetic mode/conditions are close to values for a wave mode/conditions, and then when begin to oscillate. Values themselves ΔA_0^H and ΔA_0^E are comparatively small and are characterized by amplitude and the frequency of resonance.

Let us examine the fundamental laws governing a change in the screen attenuation of wave zone from the construction of screen.

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ELECTROMAGNETIC SHADOWING OVER A WIDE RANGE OF FREQUENCIES,(U)

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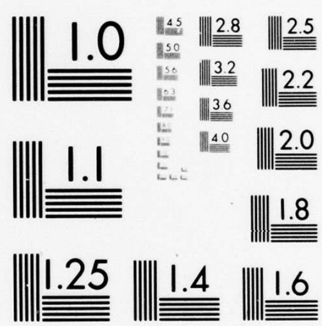
1.0
4.5
5.0
5.6
2.8
2.5
3.2
2.2
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4.0
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1.25
1.4
1.6

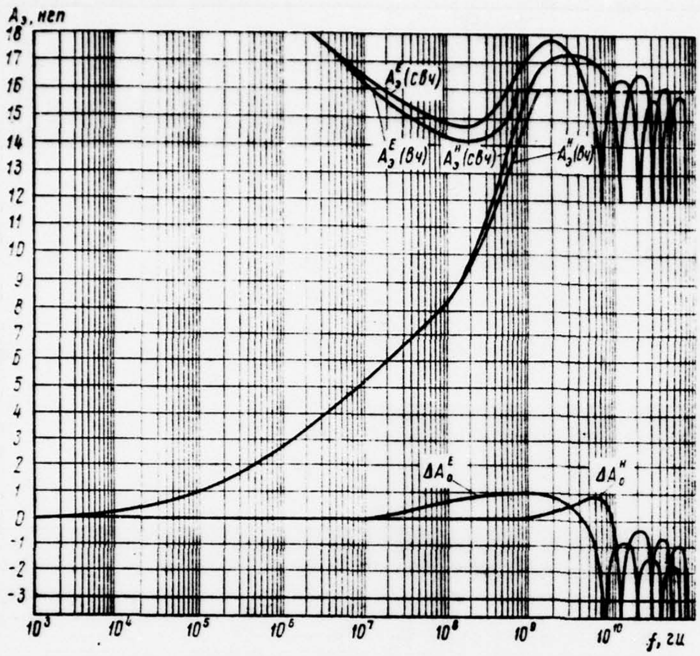

Fig. 1.19.

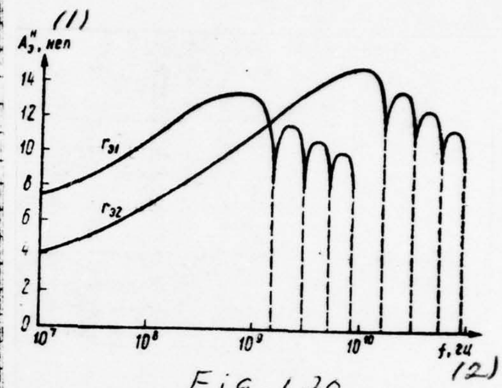

Fig. 1.20.

Fig. 1.19. Components of attenuations of shadowing in ranges of H.f. and SHF.

[Нен = Np; СВЧ = SHF; ВЧ = h.f.; гц = Hz]

Fig. 1.20. Attenuation of shadowing of magnetic field with different radii of screens.

Key: (1). Np. (2). Hz.

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Figures 1.20 gives the frequency dependence of the attenuation of the shadowing of magnetic field $A_э^H$ for a copper screen by thickness t = 0.01 mm by a radius $r_{э1}=0{,}5$ mm and $r_{э2}=5$ mm. With an increase in the radius of screen, grow/rises screening effect and resonance phenomena they are moved into the range of lower frequencies.

Figures 1.21a and b gives the frequency dependences of the attenuation of the shadowing of electrical and magnetic fields for screen with radius of 5 mm and the different thicknesses: t_1 = 0.01 mm and t_2 = 0.001 mm. From it is placed to an increase in screening effect. Moreover resonance frequencies virtually remain constant/invariable.

Figures 1.22a and b shows the dependence of the resonance frequencies of the attenuation of shadowing for electrical and magnetic fields on a change in the radius of screen. Curve 1 is related to the values of the first resonance, and curved 2, 3 and 4 - respectively to the values of the subsequent resonances. With an increase in the radius of screen, the resonance frequency decreases. So, if for a magnetic field when $r_э=10$ m the first resonance

begins with f_{01} = $1.8 \cdot 10^9$ Hz, then when $r_э$=30 m it begins with f_{01} = $5.6 \cdot 10^9$ Hz.

Table 1.10. Attenuation of shadowing for electrical and magnetic fields in wave zone (copper; $r_э$=10 mm; t = 0.01 mm).

(1) f, гц	$A_э^H$(вч) (2)	$A_э^E$(вч) (2)	$\Delta A_э^E$	$\Delta A_э^H$	$A_э^E$(свч) (3)	$A_э^H$(свч) (3)
10^2	0	35,34	0	0	35,34	0
10^3	0,00099	31,44	0	0	31,44	0,00099
10^4	0,0237	26,14	0	0	26,16	0,0237
10^5	0,9042	22,44	0	0	22,44	0,9042
10^6	3,114	20,03	0	0	20,03	3,114
10^7	5,42	17,63	0	0	17,63	5,42
10^8	8,38	16	0,1	0	16,1	8,38
$1,9 \cdot 10^9$	>17,0	>17	1,77	0,095	18,77	17,095
$4,5 \cdot 10^9$	>17,0	>17	0	0,214	17	17,214
$8,77 \cdot 10^9$	>17,0	>17	$-\infty$	0,15	$-\infty$	17,15
$1,10 \cdot 10^{10}$	>17	>17	—	0	—	17
$1,52 \cdot 10^{10}$	>17	>17	−0,576	—	16,424	—
$1,8 \cdot 10^{10}$	>17	>17	—	$-\infty$	—	$-\infty$
$2,46 \cdot 10^{10}$	>17	>17	—	−0,9	—	16,1
$2,64 \cdot 10^{10}$	>17	>17	$-\infty$	—	$-\infty$	—
$3,22 \cdot 10^{10}$	>17	>17	−1,24	—	15,75	—
$3,33 \cdot 10^{10}$	>17	>17	—	$-\infty$	—	$-\infty$
$4,08 \cdot 10^{10}$	>17	>17	$-\infty$	−1,46	$-\infty$	15,54
$4,85 \cdot 10^{10}$	>17	>17	−1,63	$-\infty$	15,37	$-\infty$
$5,65 \cdot 10^{10}$	>17	>17	$-\infty$	−1,76	$-\infty$	15,24

Note. At the frequencies of large $1\text{-}9.10^{9}$ we take A, (h.f.) = 17 Np.

Key: (1). Hz. (2). h.f. (3). SHF.

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Example of the calculation of screen. To determine the magnetic screen attenuation of the copper cylindrical screen with a thickness of 0.1 mm and with a radius of 20 mm at frequency 1 MHz.

Solution.

1. From Table 1.2; 1.3 and 1.4 we find values of wave dielectric resistance, copper and coefficient of eddy currents:

$$Z_{д} = 1138 \cdot 10^{-3}\ ом, \quad Z_{м} = \sqrt{i}\,0{,}372 \cdot 10^{-3}\ ом,$$

$$\kappa = \sqrt{i}\,21{,}21\ \frac{1}{мм}.$$

[ом = Ω]

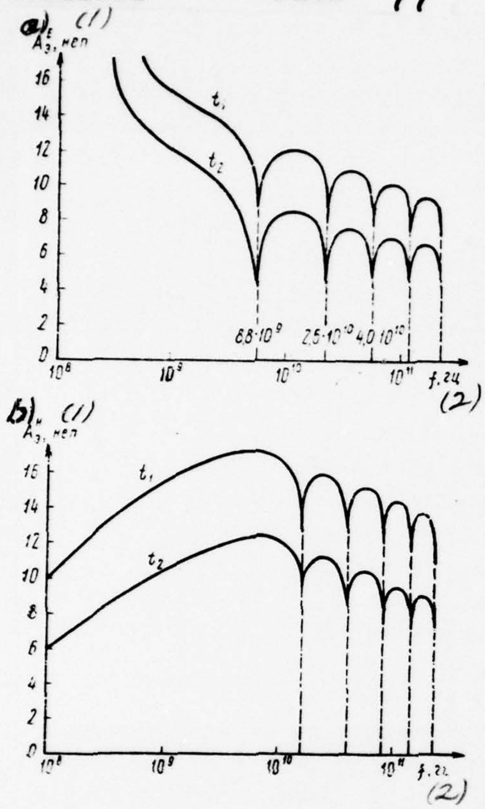

Fig. 1.21

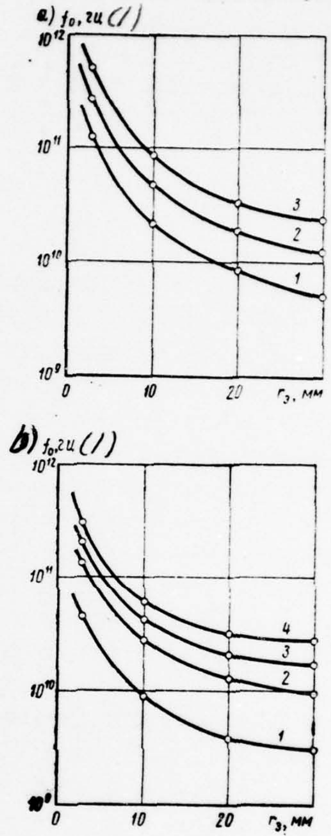

Fig. 1.22.

Fig. 1.21. Frequency dependence of attenuation of shadowing of electrical (a) and magnetic (b) fields with thickness of screen t_1 = 0.01 and t_2 = 0.001 mm and r = 5 mm.

Key: (1). Np. (2). Hz.

Fig. 1.22. Dependence of resonance frequencies of attenuation of shadowing for electrical (a) and magnetic (b) fields on

change in radius of screen.

Key: (1). Hz.

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2. We determine attenuation of absorption of screen:

$$S_n = \frac{1}{\operatorname{ch} \kappa_M t} = \frac{1}{\operatorname{ch} \sqrt{i21,21} \cdot 0,1} = \frac{1}{2,13e^{i84,6^\circ}} = 0,47e^{-i84,6^\circ},$$

$$A_n = \ln\left|\frac{1}{S_n}\right| = \ln\left|\frac{1}{0,47e^{-i84,6^\circ}}\right| = 0,75 \text{ Np}.$$

3. We determine attenuation of reflection of screen:

$$S_0 = \frac{1}{1 + \frac{1}{2}\left(\frac{Z_д}{Z_м} + \frac{Z_м}{Z_д}\right) \operatorname{th} \kappa_M t},$$

$$1 + \frac{1}{2}\left(\frac{Z_д}{Z_м} + \frac{Z_м}{Z_д}\right) = 1 + \frac{1}{2}\left(\frac{138 \cdot 10^{-3} e^{i90^\circ}}{0,372 \cdot 10^{-3} e^{i45^\circ}} + \frac{0,372 \cdot 10^{-3} e^{i45^\circ}}{138 \cdot 10^{-3} e^{i90^\circ}}\right) = 185,5e^{i45^\circ},$$

$$\operatorname{th} \kappa_M t = \operatorname{th} \sqrt{i21,21} \cdot 0,1 = 1,11e^{i1,18^\circ}.$$

Whence

$$S_0 = \frac{1}{185,5e^{i45^\circ} \cdot 1,11e^{i1,18^\circ}} = \frac{1}{205,5e^{i46,18^\circ}} = 0,00487\, e^{-i46,18^\circ}.$$

$$A_0 = \ln\left|\frac{1}{S_0}\right| = \ln\left|\frac{1}{0,00487e^{-i46,18^\circ}}\right| = 5,325 \text{ Np}.$$

4. We determine total attenuation of shadowing:

$$A_э = A_n + A_0 = 0,75 + 5,325 = 6,075 \text{ Np}.$$

Page 47. Chapter 2. SINGLE-LAYER SCREENS.

2.1. "Wave" method of determining the screening constant.

"Wave" method is based on the examination of the phenomena of shadowing with the aid of falling/incident, reflected and refracted waves on the boundaries of electrical nonconformities dielectric - metal - dielectric. In this case the shielding properties of screens are expressed as the wave characteristics of the metal from which is made the screen, and the dielectric, which surrounds screen. "wave" method allows to mathematically simply and physically convincingly present the processes, occurring in screens.

Let us determine the screening effect of single-layer screen (Fig. 2.1) by "wave" method and let us compare with the results, obtained earlier with solution by classical

method on the basis of the equations of Maxwell.

We take the thickness of screen t, the coefficient of eddy currents $\kappa=\sqrt{i\omega\mu\sigma}$. Let us assume that to the surface of screen in region I falls the wave of the source of interferences E. As a result of the nonconformity of electrical characteristics (boundary of I-II) the part of the energy will be reflected back into region I. The part of the reflected energy can be expressed by the coefficient of reflection (p_{12}) in the form $E_2 = Ep_{12}$. Another part of the energy passes into region II and, vary in proportion to to refractive index (q_{12}), will undergo attenuation according to the law $e^{-\kappa t}$. Field in region II will be determined $E_1=q_{12}e^{-\kappa t}E$. This wave in boundary of II-III partially will be reflected ($E_3=q_{12}p_{23}e^{-2\kappa t}E$) and partially it passes for screen ($E_4=q_{12}q_{23}e^{-\kappa t}E$). Wave E_3 partially passes into region I ($E_6=q_{12}q_{21}p_{23}e^{-2\kappa t}E$), a partially it will be reflected from boundary of I-II it will return conversely ($E_5=q_{12}p_{12}p_{23}e^{-3\kappa t}E$). This wave partially passes into the shielded space (region III) in the form of wave $E_8=q_{12}q_{23}p_{12}p_{23}e^{-3\kappa t}E$.

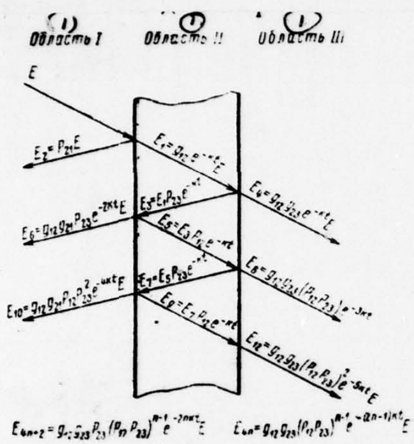

Fig. 2.1. On the calculation of screening effect of single-layer screen by "wave" method.

Key: (1). region.

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Wave E_5 on boundary of II-III gives the wave E_7, which will cause the reflected and refracted waves, and so this process can continue to infinity until waves completely damp. As a result it is possible to write for region I where operates the sum of the waves reflected, the following expression:

$$E^0 = E_2 + \sum_{n=1}^{\infty} E_{4n+2} = E_2 + \sum_{n=1}^{\infty} q_{12}q_{21}p_{23}(p_{12}p_{23})^{n-1} e^{-2n\kappa t}E. \quad (2.1a)$$

It summed up this series, we obtain

$$E^{\circ}=\left(p_{12}+\frac{q_{12}q_{21}p_{23}\,e^{-2\varkappa t}}{1-p_{12}p_{23}\,e^{-2\varkappa t}}\right)E. \qquad (2.1b)$$

Let us hence determine the resulting coefficient of reflection (reaction) of the screen

$$P=\frac{E^{\circ}}{E}=p_{12}+\frac{q_{12}q_{21}p_{23}\,e^{-2\varkappa t}}{1-p_{12}p_{23}\,e^{-2\varkappa t}}. \qquad (2.1c)$$

In region III in the shielded space, will operate a whole series of transmitted through the screen waves of the type E_{4n}: $E^{э}=\sum_{n=1}^{\infty}E_{4n}=\sum_{n=1}^{\infty}q_{12}q_{23}(p_{12}p_{23})^{n-1}\,e^{-(2n-1)\varkappa t}E.$

$$S=\frac{E^{э}}{E}=\frac{q_{12}q_{23}\,e^{-\varkappa t}}{1-p_{12}p_{23}\,e^{-2\varkappa t}}. \qquad (2.2)$$

Then screening constant is equal to

tab we convert the obtained expressions for P and S. It is known that the refractive indices q and of reflection r are expressed as the **wave characteristics** of the conjugated/combined **mediums** Z_A and Z_B:

$$q=\frac{2Z_A}{Z_A+Z_B};\quad p=\frac{Z_A-Z_B}{Z_A+Z_B}. \tag{2.3}$$

Bearing in mind that in our case $Z_1 = Z_3$, we will obtain:

$$\left.\begin{aligned} q_{21}&=\frac{2Z_2}{Z_1+Z_2};\quad q_{12}=\frac{2Z_1}{Z_2+Z_1};\\ p_{21}&=\frac{Z_1-Z_2}{Z_1+Z_2};\quad p_{12}=\frac{Z_2-Z_1}{Z_2+Z_1},\end{aligned}\right\}. \tag{2.4}$$

where Z_1 - **wave** dielectric resistance ($Z_д$), a Z_2 - the wave impedance of **metal** ($Z_м$).

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After substituting values of q and p in (2.2), we will obtain

$$S=\frac{q_{12}q_{21}e^{-\varkappa t}}{1-p_{12}p_{21}e^{-2\varkappa t}}=\frac{2Z_1\cdot 2Z_2}{(Z_1+Z_2)}e^{-\varkappa t}\cdot\frac{1}{1-\left(\frac{Z_2-Z_1}{Z_2+Z_1}\right)^2e^{-2\varkappa t}},$$

or

$$S=\frac{1}{\frac{(Z_1+Z_2)^2}{Z_1Z_2}\cdot\frac{e^{\varkappa t}}{4}-\frac{(Z_2-Z_1)^2}{Z_2Z_1}\cdot\frac{e^{-\varkappa t}}{4}}.$$

Converting this expression, we will obtain

$$S=\frac{1}{\frac{e^{\kappa t}}{2}+\frac{e^{-\kappa t}}{2}+\frac{e^{\kappa t}}{4}\cdot\frac{Z_1^2+Z_2^2}{Z_1Z_2}-\frac{e^{-\kappa t}}{4}\cdot\frac{Z_1^2+Z_2^2}{Z_1Z_2}}.$$

Passing to hyperbolic functions, we will obtain

$$S=\frac{1}{\mathrm{ch}\,\kappa t+\frac{Z_1^2+Z_2^2}{2Z_1Z_2}\,\mathrm{sh}\,\kappa t}=\frac{1}{\mathrm{ch}\,\kappa t}\cdot\frac{1}{1+\frac{1}{2}\left(\frac{Z_1}{Z_2}+\frac{Z_2}{Z_1}\right)\mathrm{th}\,\kappa t} \qquad (2.5)$$

or it is final

$$S=\frac{1}{\mathrm{ch}\,\kappa t}\cdot\frac{1}{1+\frac{1}{2}\left(\frac{Z_д}{Z_м}+\frac{Z_м}{Z_д}\right)\mathrm{th}\,\kappa t}. \qquad (2.6)$$

Comparing (2.6) with formula (1.47), we note that the "wave" method and the classical method of the solution to differential equations give identical result.

2.2. Coefficient of the reaction of screen.

Electromagnetic screen, shielding circuits and ducts from interferences, simultaneously exerts essential influence on

its own parameters of the shielded cell/elements (circuits, ducts), after redistributing internal electromagnetic field and changing the conditions of the passage of signals along these circuits. This phenomenon is caused by the reaction of screen, which is led to a change in its own parameters of the shielded cell/elements. In this case, change both parameters of the chain transfer and ducts (R, L, C, G) and the parameters of the effect which include the electrical $(K=q+i\omega\dot{\kappa})$ and magnetic $(M=r+i\omega\dot{m})$ of communication/connection.

The effect of screen on the electrical characteristics of circuits and ducts, included into screen, can be determined with the aid of the coefficient of the reaction of screen P. Electromagnetic screen is characterized by two parameters: the screening constant S, which determine degree and the fundamental laws governing of a change in electromagnetic field outside screen, and by the coefficient of reaction P, which determine degree and the fundamental laws governing a change in electromagnetic field within screen. Both parameters are organically interconnected and can be mathematically determined one of another.

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Only the combined examination of both factors S and P can give the proper representation of the processes of the shadowing of the system being investigated and make it possible to select the optimum construction of electromagnetic screen, which is especially important for communication cables where the large number of circuits is arrange/located in immediate proximity of screen and experience/tests its electromagnetic control.

Parameter S makes it possible to consider the shielding ability of system and the degree of a decrease in the field of the interferences in the effect of one electrical circuit on another. Parameter P makes it possible to investigate from screen the field reflected and the degree of its effect on the natural electrical characteristics of circuits, contained screen.

The effect of reaction to its own parameters of circuits and ducts, contained screen, can be both negative and positive. Under specific conditions and the design relationship/ratios of screens, their reaction can improve the electrical characteristics of the shielded cell/elements. Therefore during screens, one should attempt to obtain maximum screening effect and the most advantageous parameters

of the reaction of screens. The coefficient of reaction is determined by "wave" method and is expressed in the form of the ratio of the reflected field E^0 to basic field E:

$$P=\frac{E^0}{E}. \qquad (2.7)$$

Converting expressions (2.1a-2.1c) taking into account values of q and p, we will obtain the final coefficient of reaction in the form

$$P=\frac{\frac{1}{2}\left(\frac{Z_Д}{Z_М}-\frac{Z_М}{Z_Д}\right)\operatorname{th}\kappa t}{1+\frac{1}{2}\left(\frac{Z_Д}{Z_М}+\frac{Z_М}{Z_Д}\right)\operatorname{th}\kappa t}, \qquad (2.8)$$

where $Z_Д$ — wave dielectric resistance; $Z_М$ — is wave impedance of metal; t is thickness of screen; $\kappa=\sqrt{i\omega\mu\sigma}$ — the coefficient of eddy currents.

Analyzing formula (2.8), it can be noted that the coefficient of reaction the greater, the greater the nonconformity between the wave dielectric resistance $Z_Д$ and of metal $Z_М$. During the weak screening effect P = 0, i.e., the screen does not reflect energy. During the powerful screening effect of the magnetostatic screens P = -1, and of electromagnetic P = +1.

Nonmagnetic and magnetic screens possess the different reflecting properties, which depend on the shielding nature of nonmagnetic and magnetic materials. This position is visually illustrated by Table 2.1 and Fig. 2.2, where corrected values of the coefficients of the reaction of steel and copper screens. The coefficient of the reaction of copper varies from 0 to 1; P of steel depending on frequency undergoes more complex change.

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In the range of low frequencies, approximately to 7-8 kHz, the coefficient of reaction has negative value, then it passes through 0 and begins to grow/rise, being fixed to unity. Thus, P of steel has two characteristic zones. The first zone - the negative values P (from -1 to 0) - corresponds to the magnetostatic mode/conditions of shadowing; in it small surface effect and equivalent depth of penetration are greater than the thickness of screen ($\theta >$ t). The second zone - the positive values P (from 0 to +1) - corresponds to the electromagnetic mode/conditions of screen. Equivalent depth of penetration is less than the

thickness of screen $(\theta<t)$. Surface effect is considerably increased. Transition of one zone to another occurs with kt ~ 0.7.

Copper screen, as all other nonmagnetic screens, has only positive values of P and operates on the principle of electromagnetic shadowing.

Table 2.1. Data of the calculation of the coefficients of reaction.

(1) f, кгц	(2) Медь, $t=0,08$ мм		(3) Сталь, $t=0,1$ мм	
	$Pe^{i\varphi}$	$P_д+iP_м$	$Pe^{i\varphi}$	$P_д+iP_м$
0	0 90°00′	0 +0	1,0 180°00′	−1 0
0,1	0,0310 82°24′	0 +0,03	0,2181 178°34′	−0,22 +0,08
1	0,2998 76°11′	0,07 +0,29	0,2246 167°13′	−0,2 +0,09
10	0,9499 17°39′	0,91 +0,28	0,3927 92°00′	−0,014+0,39
20	0,9845 9°04′	0,97 +0,15	0,5447 59°52′	0,28 +0,47
40	0,9935 4°33′	0,99 +0,07	0,6577 35°07′	0,53 +0,37
60	0,9958 3°02′	0,995 +0,05	0,6940 25°35′	0,63 +0,29
80	0,9960 2°10′	0,996 +0,04	0,7145 22°16′	0,66 +0,27
100	0,9962 1°49′	0,96 +0,03	0,7299 18°51′	0,69 +0,24
110	0,9965 1°43′	0,9965+0,027	0,7371 17°55′	0,70 +0,23
130	0,9967 1°36′	0,9967+0,025	0,7498 16°40′	0,72 +0,22
150	0,9968 1°27′	0,9968+0,023	0,7616 15°28′	0,73 +0,2
	1,0 0°00′	1,0 +0	1,0 0°00′	1,0 +0

Key: (1). f, kHz. (2). Copper. (3). Steel.

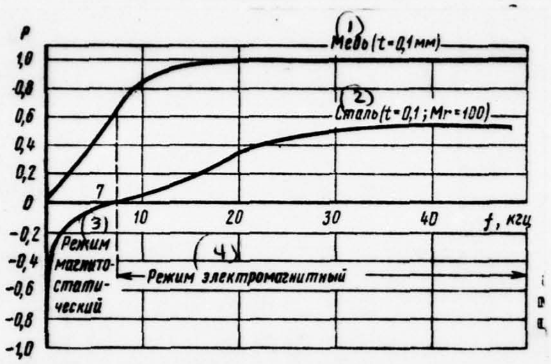

Fig. 2.2. Frequency dependence of coefficient of reaction of copper and steel screen.

Key: (1). Copper. (2). steel. (3). Mode/conditions magnetostatic. (4). Mode/conditions electromagnetic.

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As can be seen from curve/graph, the coefficient of the reaction of copper is greater than steel, and already, beginning with frequency f = 20 kHz, is almost equal to unity. To this are explained the high characteristics of

the copper and other nonmagnetic screens on the attenuation of reflection (A_0 copper substantially more A_0 steel). The reactive components of P have a maximum for steel with f = 20 kHz, and for copper with f = 1.9 kHz.

From the formulas of calculation P, it is evident that because of th from composite argument (kt) the module/modulus of the coefficient of reaction has oscillating-increasing character (Fig. 2.3), moreover value P (formula 2.8) it increases with an increase in the coefficient of eddy currents $(\kappa=\sqrt{i\omega\mu\sigma})$ and the thickness of screen (t). At the large values of t, the coefficient of reaction does not depend on a further increase in the thickness of screen. This means that in this case the thickness of screen is greater than the equivalent depth of penetration of field into the metallic thickness of screen (t > θ).

At the large values kt the reaction of screen can be determined by the formula

$$P=\frac{Z_{\text{д}}-Z_{\text{м}}}{Z_{\text{д}}+Z_{\text{м}}}. \qquad (2.9)$$

This formula completely coincides with the formula of the calculation of reflection coefficient, widely utilized

for the investigation of the phenomena of heterogeneity in the theory of electrical circuits.

2.3. Analogy between to the processes of shadowing and by transmittings of energy on electrical circuits.

The physical essence of the phenomena, which occur in electromagnetic screens, in many respects is similar to the processes, which occur in electrical circuits during the propagation of energy on uniform lines with mismatched loads. Therefore is of interest the comparison of the methods of the calculation of the screens, which are based on the solution to the fundamental equations of electrodynamics, with the methods of circuit design, used in electrical engineering and in the courses of the theory of electric coupling (Fig. 2.4). For this, we convert (2.6) and (2.8):

$$\left.\begin{aligned} A_{э} &= A_{п} + A_{о} = \ln\left|\frac{1}{S}\right| = \ln\left|\operatorname{ch}\kappa t\left[1 + \frac{1}{2}\left(N + \frac{1}{N}\right)\operatorname{th}\kappa t\right]\right| \\ P &= \frac{\frac{1}{2}\left(N - \frac{1}{N}\right)\operatorname{th}\kappa t}{1 + \frac{1}{2}\left(N + \frac{1}{N}\right)\operatorname{th}\kappa t} \end{aligned}\right\}, \quad (2.10)$$

where $N = \frac{Z_{д}}{Z_{м}}$.

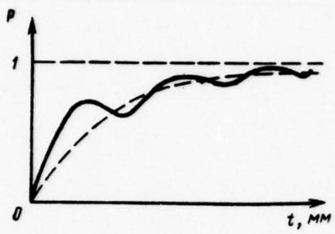

Fig. 2.3. Character of change in coefficients of reaction with increase in thickness of screen.

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Passing from the recording in hyperbolic functions and to exponential functions, we will obtain value $A_э$ in the following form:

$$A_э = \ln \left| \frac{e^{\kappa t}}{4}\left(2+N+\frac{1}{N}\right)+\frac{e^{-\kappa t}}{4}\left(2-N-\frac{1}{N}\right)\right| = \\ = \ln \left| e^{\kappa t}\frac{(N+1)^2}{4N} - e^{-\kappa t}\frac{(N-1)^2}{4N}\right|.$$

Replacing N with the values of wave impedance and converting expression, we will obtain

$$A_э = \ln \left| e^{\kappa t}\left(\frac{Z_д + Z_м}{2\sqrt{Z_д Z_м}}\right)^2 - e^{-\kappa t}\left(\frac{Z_д - Z_м}{2\sqrt{Z_д Z_м}}\right)^2\right|.$$

After carrying the first term for brackets and piecemeal taking the logarithm of, we will obtain

$$A_э = \frac{\kappa t}{\sqrt{2}} + 2\ln\left|\frac{Z_л + Z_м}{2\sqrt{Z_л Z_м}}\right| + \ln\left|1 - \left(\frac{Z_л - Z_м}{Z_л + Z_м}\right)^2 e^{-2\kappa t}\right|. \quad (2.11)$$

This formula completely corresponds tc the formula of the calculation of the attenuation of the circuit with mismatched loads, widely used in theory of the electrical circuits:

$$a_р = \alpha l + 2\ln\left|\frac{Z_A + Z_B}{2\sqrt{Z_A Z_B}}\right| + \ln\left|1 - \left(\frac{Z_A - Z_B}{Z_A + Z_B}\right)^2 e^{-2\gamma l}\right|,$$

where Z_B and Z_A — are the line characteristic and load respectively; l— is length of line; γ is a propagation factor. This formula consists of three terms, where first term is the non-reflection attenuation of line (αl), the second - supplementary attenuation of reflection as a result of the impedance mismatch of loads with the resistor/resistance of lines, the third is supplementary attenuation of reflection due to the interaction of mismatches in the beginning and end/lead of the subsequent component waves.

The coefficient of the reaction of screen can be converted as follows:

$$P=\frac{\frac{1}{2}\left(N-\frac{1}{N}\right)\operatorname{th}\kappa t}{1+\frac{1}{2}\left(N+\frac{1}{N}\right)\operatorname{th}\kappa t}=\frac{(N-1)(N+1)\left(e^{\kappa t}-e^{-\kappa t}\right)}{(N+1)^2e^{\kappa t}-(N-1)^2e^{-\kappa t}}.$$

Substituting $N=\frac{Z_д}{Z_м}$, we will obtain

$$P=\frac{Z_д-Z_м}{Z_д+Z_м}\cdot\frac{e^{\kappa t}-e^{-\kappa t}}{e^{\kappa t}-e^{-\kappa t}\left(\frac{Z_д-Z_м}{Z_д+Z_м}\right)^2}.$$

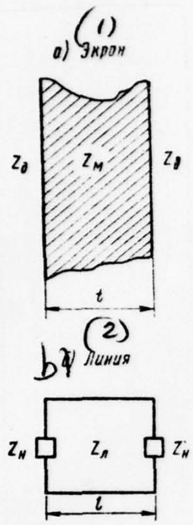

Fig. 2.4. To comparison of methods of calculation of screens and circuits.

Key: (1). Screen. (2). Line.

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During the considerable energy absorption by the screen when kt > 3 (reflected energy does not exceed 5o/o), we will obtain

$$P = \frac{N-1}{N+1} = \frac{Z_Д - Z_М}{Z_Д + Z_М}. \qquad (2.12)$$

This be the value of reflection coefficient, widely

utilized for the investigation of the phenomena of heterogeneities in electrical circuits. The physical essence of the phenomena of shadowing in question and the obtained mathematical analogy make it possible to make following conclusions. The process of the passage of electromagnetic energy through the screen is analogous to the process of the propagation of energy along electrical circuit. Difference consists in the fact that in lines is investigated energy of the transmission, and in screens - energy of effect. During the investigation of screens, is examined the motion of energy not along line, but it is perpendicular to it, from perturbation source (circuit) and to screen it is further through the screen into the shielded space.

So both with propagation of electromagnetic energy along non-uniform circuit and during motion in radial direction is necessary to consider two factors: the attenuation of energy in metallic thicker screen $(A_п)$ and the attenuation of reflection at a boundary dielectric - screen - dielectric $(A_о)$. $A_п$ in connection with the theory of lines corresponds to the attenuation of energy in line itself (αl), a A_0 - because of the nonconformity of the wave impedance of the different sections of non-uniform circuit. Electromagnetic

energy, after achieving screen, partially is passed through it, somewhat attenuating in this case, and partially it is reflected in the first boundary dielectric - screen. In boundary the screen - dielectric the part of the energy again is reflected, and part penetrates on screen.

Reflection and the passage of the electromagnetic energy through the screen can be presented in the form of repeated process and mathematically it is possible to express in the form of infinite series. In analyzed formula (2.11) the first term characterizes attenuation in thicker than the screen, the second - screen attenuation because of reflection at a boundary (dielectric - screen - dielectric) fundamental component wave, and the third term considers the attenuation, which occurs because of repeated reflections at a boundary of the subsequent component waves. The decisive role during shadowing have the first of two members.

During the energy transfer on wires, the effect of reflection is extremely undesirable, while during shadowing the presence of this effect gives positive result. The more powerful the reflection of energy on boundaries dielectric - screen - dielectric, the the lesser part of the energy penetrates the shielded space.

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For a screen with high attenuation (kt > .3), the formula of shadowing will take the form: $S = \dfrac{1}{\frac{1}{2} e^{\kappa t}\left[1+\frac{1}{2}\left(N+\frac{1}{N}\right)\right]}$,

and respectively screen attenuation will be $A_э = \ln\left|\frac{1}{S}\right| = \ln\left|e^{\kappa t}\left[1+\frac{1}{2}\left(N+\frac{1}{N}\right)\right]\right|$. This formula can be given to the form, taken for the calculation of the electrical circuits:

$$A_э = \ln\left|e^{\kappa t}\frac{(N+1)^2}{4N}\right| = \frac{|\kappa|}{\sqrt{2}}t + 2\ln\left|\frac{Z_д + Z_м}{2\sqrt{Z_д Z_м}}\right|. \qquad (2.13)$$

The obtained result has very convincing physical treatment. With screen with high attenuation screen attenuation will consist only of the attenuation of energy because of energy absorption of metal (1st term) and attenuation because of reflection at a boundary (2nd term). The third term of formula (2.11), that characterizes the screen attenuation, which occurs because of the multiple reflections of the subsequent components, here does not participate. This is explained to the facts that in this screen the subsequent components cannot influence the value of screening effect, since as a result of high attenuation their value is very low.

2.4. Operating principle of magnetic and nonmagnetic screens.

Magnetic screens with direct current and in the range of low frequencies operate as magnetostatic according to the principle of the closing/shorting of magnetic field in thicker than the screen due to its increased magnetoconductance [μ = 100 and is above, formula (1.44)]. With an increase of frequency, grow/rises the role of eddy currents, occurs the displacement of magnetic field from the thickness of screen and its increased magnetoconductance loses its value. Screen passes to the electromagnetic operating mode and operates just as nonmagnetic screen, because of eddy currents in thicker than the screen.

Nonmagnetic screens in all frequency spectrum operate as electromagnetic, i.e., according to the principle of the onset in them of the eddy currents. With direct current they do not possess the electromagnetic shielding properties. With an increase of frequency, screening effect grow/rises [formula (1.45)].

The graph/diagram of the frequency dependence of magnetic and nonmagnetic screens is given in Fig. 2.5. On curve/graph are visible three characteristic frequency zones. In the first zone from 0 to f = 3-10 kHz, magnetic screen works in magnetostatic mode/conditions and possesses the best shielding properties, than nonmagnetic screen. In the second and third zones both screens are located in electromagnetic mode/conditions. But in the second zone from f_1 to f_2 ~~ 10^6 Hz nonmagnetic screen has larger screening effect than magnetic one, but in the third zone from f_2 = 10^6 Hz, is above of curve/graph clearly evidently the superiority of steel screen. This is caused by the facts that magnetic screens absorb well energy and they very badly/poorly reflect it $|A_п > A_о|$. Of nonmagnetic materials, on the contrary, $A_о > A_п$.

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Frequency 0.8-1 MHz is the frequency of section, lower than which predominates the attenuation of reflection above the attenuation of absorption ($A_о > A_п$), a above, vice versa $A_п > A_о$. Therefore in the lower frequency region, where screening effect is determined by the attenuation of reflection, copper screen is noticeably more effective than steel. In

the range of high frequencies (0.8-1 MHz is above), where begins to predominate the attenuation of absorption, it is better to apply steel screen. This position is visually illustrated by Fig. 2.6, where is given the calculation of values $A_п$, $A_о$ and $A_э$, for the copper and steel screens with a thickness of 0.1 mm.

2.5. Comparison of the screens of different constructions.

In technology of communication/connection and radio engineering, have extensive application all three fundamental structural/design varieties of the screens: flat/plane, cylindrical and spherical (Fig. 2.7). The screening constant of these screens is determined by formula [2]

$$S = \frac{1}{\operatorname{ch} \kappa t} \cdot \frac{1}{1 + \frac{1}{2}\left(N + \frac{1}{N}\right) \operatorname{th} \kappa t},$$

where $N = Z_д/Z_м$.

Difference consists only of the value of the wave impedance which enters in parameter N. The wave impedance, exerted by dielectric medium (air) to the different forms of waves, is expressed by the formulas:

$$\left.\begin{array}{r} \text{(1) для плоской волны } Z_{\text{д}}^{\text{п}} = i\,\omega\mu\,2r_{э} \left(\text{(1a) где } r_{э} = \frac{l}{2}\right) \\ \text{(2) для цилиндрической волны } Z_{\text{д}}^{\text{ц}} = \frac{i\,\omega\mu\,r_{э}}{n} \\ \text{(3) для сферической волны } Z_{\text{д}}^{\text{с}} = \frac{i\,\omega\mu\,r_{э}}{\sqrt{2}\,n} \end{array}\right\} . \quad (2.14)$$

Key: (1). for a plane wave. (1A). where. (2). for cylindrical wave. (3). for a spherical wave.

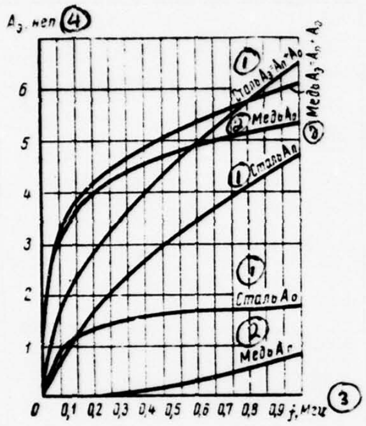

Fig. 2.6

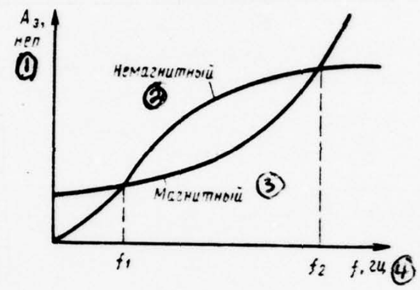

Fig. 2.5

Fig. 2.5. Effectiveness of shadowing of nonmagnetic and magnetic screens.

Key: (1). Np. (2). Nonmagnetic. (3). Magnetic. (4.) f, gg.

Fig. 2.6. Screen attenuation of absorption $(A_п)$ and of reflection (A_o) of copper and steel screens.

Key: (1). Steel. (2). Copper. (3) MHz. (4). Np.

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The wave impedance of metal is determined by expression $Z_м = \sqrt{i\omega\mu/\sigma}$. Comparing the values of the wave dielectric resistance of flat/plane, cylindrical and spherical screens, it can be noted that they are expressed by relationship/ratio (with n = 1): $Z^п_д : Z^ц_д : Z^с_д = 1 : \frac{1}{2} : \frac{1}{3}$. For the virtually interesting us frequency spectra and the constructions of screens there is inequality N > 1/N. Then the effectiveness of the shadowing of flat/plane, cylindrical and spherical screens will be expressed by the approximately following relationship/ratio:

$$S^п : S^ц : S^с = 1 : 2 : 3. \qquad (2.15)$$

Thus, if the screening constant of flat/plane screen is accepted for unity, then the screening constant of cylinder will be two times of more than $S^ц = 2S^п$, a sphere (sphere) three times $- S^с = 3S^п$. Since the screening effect of screen the greater, the lesser value S, on screening effect the indicated three fundamental structural/design varieties of screens it is possible to arrange in the following sequence: flat/plane screen, cylinder, sphere. This

relationship/ratio is correct for the screens, prepared from identical metal and with the equal wall thicknesses, moreover the distance between the parallel plates of flat/plane screen equal to the diameter of spherical or cylindrical screens $(l=2r_э)$.

The advantage of cylinder in compariscn with sphere and, in turn, flat/plane screen in comparison with both these constructions is caused by the facts that the plane wave has better relationship/ratio of the wave dielectric resistance and metal $N=Z_д/Z_м$, and therefore occurs larger wave reflection on boundaries dielectric - screen - dielectric and with respect is provided larger screening effect of reflection (S_0). Taking into account that screen attenuation A_0 is connected with screening constant formula $A_0=\ln\left|\frac{1}{S}\right|$ and utilizing an equivalent given above $S^п:S^ц:S^с=1:2:3$, it is possible to determine ccmparative effectiveness of different screens (flat/plane, cylindrical, spherical) in nepers.

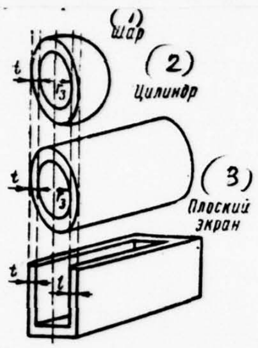

Fig. 2.7. Structural/design forms of screens.

Key: (1). Sphere. (2). Cylinder. (3). Flat/plane screen.

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Accepting screening effect of flat/plane screen as original value, we will obtain

$$A_э^п = \ln\left|\frac{1}{S^п}\right|,$$

$$A_э^ц = \ln\left|\frac{1}{S^ц}\right| = \ln\left|\frac{1}{2S^п}\right| = A_э^п - \ln 2 = A_э^п - 0{,}7,$$

of the form of screen is very valuable fact, since it allows in the practice of calculation and constructions of screens, and also during the determination of the effectiveness of the existing screens to apply the given formulas of the shadowing of flat/plane, cylindrical and spherical screens to the screens, close to them in construction. Thus, for instance, if there is a longitudinal screen with rectangular cross section, then it it is possible to replace with cylindrical screen, if its sides are approximately equal, and to planes, if it has sharply pronounced form of rectangle. The screens of the different layout, which have by all three coordinates almost differing extent, one should for calculation replace by equivalent spherical screen.

For magnetic screens operates reverse/inverse law. In this case between the screening constants of flat/plane, cylindrical and spherical screens, there is the following equivalent:

$$S^{\text{п}}:S^{\text{ц}}:S^{\text{c}}=1:\frac{1}{2}:\frac{1}{3}, \qquad (2.16)$$

i.e. on screening effect on the first place is located sphere, then cylinder and finally flat/plane screen. This position has the following physical explanation. Magnetostatic

screen operates on the principle of the closing/shorting of magnetic flux in magnetic mass of screen. The lesser the resistor/resistance of screen to this flow, that more screening effect. The construction of screen in the form of sphere or cylinder more fully satisfies this requirement in comparison with flat/plane screen.

Page 59. 2.6. Screening effect of shells of relatively outside interferences.

Previously given theory and the derived formulas are valid only for the shadowing of bilateral circuits, which are located in the common/general/total joining of cable, when there is no ground effect and the distance between circuits (but), as a rule, it is less than distance from circuits to the earth/ground (h), i.e., a < h. Screening effect is caused only by the attenuation of absorption A_n and by the attenuation of reflection A_0. These phenomena are connected with vortex/eddy transverse currents in the shielding shell.

If the distance between that which affects and that subjected to effect circuits is more their distance of the earth/ground (a > h) or if is utilized asymmetric system (with the earth/ground as the return conductor), then, besides components A_n and A_0, caused by transverse currents, one should consider also the screening effect caused by the longitudinal currents, flowing in the shielding shell $A_\text{:}$. The longitudinal currents, induced by the affecting circuit, create in the shielding shell the reverse field of

reaction, the weakening field of interferences. Screening effect, caused by longitudinal currents, reaches the significant magnitude in the case of the grounding of the shielding shell. This phenomenon occurs in metal cable sheathings during the shadowing the latter from the external sources of the interferences, for example, of the high-wave lines, contact circuits of the electrified transport, powerful radio stations and other equipment/devices, which create the external mixing field.

Screening effect of metal shells in the effect of the external sources of the interferences (Fig. 2.8) will be defined as $A_э=A_п+A_о+A_z$. Values $A_п$ and $A_о$ see in formula (2.10).

Let us examine screening effect A_z, caused by the longitudinal currents metalclad, which take place on circuit the earth/ground - shell - the earth/ground.

The screening constant of metal cable sheathing relatively outside interferences is determined by formula [7]

$$S_{вн}=\frac{Z_{12}}{Z_{об}}, \qquad (2.17)$$

where Z_{12} is coupling resistance of the shielding shell; $Z_{об}$ — is impedance of circuit "shell-ground".

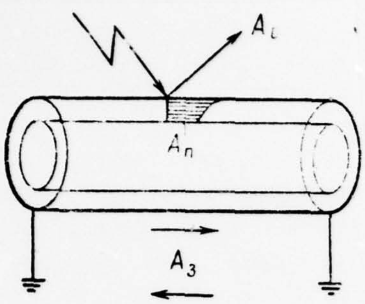

Fig. 2.8. To determination of screening effect of relatively outside interferences.

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Value $Z_{об}$ is composed of the internal resistance of the shielding shell $Z_э$ and of resistor/resistance Z_{BH}, caused by magnetic field, caused by the current, which takes place on the shell

$$Z_{об} = Z_э + Z_{BH} = Z_э + i\omega L_{BH}, \qquad (2.18)$$

where L_{BH} — is external inductance of circuit "shell is the earth/ground". Then

$$S_{BH} = \frac{Z_{12}}{Z_э + i\omega L_{BH}} \qquad (2.19)$$

or

$$S = \frac{Z_{12}}{Z_э} \frac{Z_э}{Z_э + i\omega L_{BH}}. \qquad (2.20)$$

The attenuation of shadowing will be determined as follows:

$$A_{\text{э вн}} = \ln\left|\frac{1}{S_{\text{вн}}}\right| = \ln\left|\frac{Z_{\text{э}}}{Z_{12}}\right| + \ln\left|1+\frac{i\omega L_{\text{вн}}}{Z_{\text{э}}}\right|. \qquad (2.21)$$

First term of this expression corresponds to the attenuation of absorption $A_{\text{п}}$. It is really/actually:

coupling resistance

$$Z_{12} = \frac{1}{2\pi\sqrt{r_1 r_2}} Z_{\text{м}} \frac{1}{\operatorname{sh}\kappa t}, \qquad (2.22)$$

the resistor/resistance of the shell

$$Z_{\text{э}} = \frac{1}{2\pi r_2} Z_{\text{м}} \frac{1}{\operatorname{th}\kappa t}, \qquad (2.23)$$

where $Z_{\text{м}} = \sqrt{i\omega\mu/\sigma}$ — the wave impedance of metal; $\kappa = \sqrt{i\omega\mu\sigma}$ — - the coefficient of eddy currents; t is thickness of the shielding shell; r_1, r_2 - inside and external radii of shell. Then $\ln\left|\frac{Z_{\text{э}}}{Z_{12}}\right| = \ln|\operatorname{ch}\kappa t| = A_{\text{п}}$. The attenuation of the shadowing of shell in the mode/conditions of protection from outside interferences will be

$$A_{\text{э вн}} = \ln|\operatorname{ch}\kappa t| + \ln\left|1+\frac{i\omega L_{\text{вн}}}{Z_{\text{э}}}\right| = \ln|\operatorname{ch}\kappa t| + \ln\left|1+\frac{i\omega L_{\text{вн}} 2\pi r \operatorname{th}\kappa t}{Z_{\text{м}}}\right|. \qquad (2.24)$$

This expression is included all three components of the

screening effect: $A_{э.вн}=A_п+A_о+A_z$.

The attenuation this same of shell in the mode/conditions of protection from interferences of bilateral circuits it is possible to determine of expression $A_э=\ln|\mathrm{ch}\,\kappa t|+\ln\left|1+\frac{1}{2}\frac{Z_Д}{Z_м}\mathrm{th}\,\kappa t\right|$, where the first term - the attenuation of absorption ($A_п$), a the second - the attenuation of reflection ($A_о$), i.e., $A_э=A_п+A_о$.

For determining value A_z compare these two formulas $A_{э.вн}$ and $A_э$:

$$A_{э\,вн}=A_э+A_z, \tag{2.25}$$

where

$$A_z=\ln\left|\frac{1+i\omega L_{вн}\frac{2\pi r}{Z_м}\mathrm{th}\,\kappa t}{1+\frac{1}{2}\frac{Z_Д}{Z_м}\mathrm{th}\,\kappa t}\right|. \tag{2.26}$$

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We convert expression (2.26) in connection with high-frequency and low-frequency ranges. For a low-frequency range (with kt ≤ 0.25) approximately to 3 kHz, ,

bearing in mind that th kt ~~ kt, $Z_Д/Z_М=\kappa r$, $\kappa/Z_М=\sigma$, we will obtain

$$A_z=\ln\left|\frac{1+i\omega L_{вн}\frac{2\pi r}{Z_М}\operatorname{th}\kappa t}{1+\frac{1}{2}\frac{Z_Д}{Z_М}\operatorname{th}\kappa t}\right|=\ln\left|\frac{1+i\omega L_{вн}2\pi r\sigma t}{1+\frac{1}{2}\kappa^2\sigma t}\right|. \quad (2.27)$$

This expression to expedient convert and to express by parameter R_0 (resistor/resistance of shell). Bearing in mind that the resistor/resistance of shell to direct current equally to $R_0=\frac{1}{2\pi r\sigma t}$, we will obtain

$$A_z=\ln\left|\frac{1+\frac{i\omega L_{вн}}{R_0}}{1+\frac{i\omega\mu_a}{4\pi R_0}}\right|$$

or

$$A_z=\ln\left|\frac{R_0+i\omega L_{вн}}{R_0+\frac{i\omega\mu_a}{4\pi}}\right|. \quad (2.28)$$

Since $\mu_a=\mu_0\mu=4\pi 10^{-7}\mu$, H/m,

$$A_z=\ln\left|\frac{R_0+i\omega L_{вн}}{R_0+i\omega\mu 10^{-7}}\right|, \overset{(1)}{неп.}$$

Key: (1). Np.

For a high-frequency range (with kt > 3), beginning approximately from 10 kHz, bearing in mind that the second term is greater than one, we will obtain

$$A_z = \ln\left|\frac{i\omega L_{вн}\frac{2\pi r}{Z_м}\ \mathrm{th}\ \kappa t}{\frac{1}{2}\frac{Z_д}{Z_м}\ \mathrm{th}\ \kappa t}\right| = \ln\left|\frac{i\omega L_{вн} 4\pi r}{Z_д}\right|. \qquad (2.29)$$

Since wave dielectric resistance $Z_д = i\omega\mu_0 r$.

$$A_z = \ln\left|4\pi\frac{L_{вн}}{\mu_0}\right| = \ln\left|4\pi\frac{L_{вн}}{4\pi 10^{-7}}\right| = \ln|L_{вн} 10^7|,\ \overset{(1)}{неп}, \qquad (2.30)$$

Key: (1). Np. where $L_{вн}$ — is external inductance of circuit "shell-ground", H/m, determined by formula:

$$L_{вн} = \left[\ln\frac{1.72}{\omega\mu_з\sigma_з hD} - i\frac{\pi}{2}\right]10^{-7},\ \overset{(1)}{гн/м}, \qquad (2.31)$$

Key: (1). H/m.

where h is a depth of the laying of cable, m; D - the diameter of cable, mm; σ is the specific conductivity of the earth/ground, S/m; $\mu_з$ - magnetic permeability of the earth/ground, equal approximately $\mu_0 = 4\pi\cdot10^{-7}$ H/m. Bearing in mind that the external inductance of shell is equal for the tone frequencies approximately $2\cdot10^{-3}$ H/m ($2\cdot10^{-6}$ H/m), we will obtain the attenuation of shadowing because of the

longitudinal currents: $A_z = \ln[L_{BH} \cdot 10^7] = \ln[2 \cdot 10^{-6} \cdot 10^7] = 3$ Np.

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Figures 2.9 gives computed values A_z. Here for a comparison are shown values $A_э$ and $A_{э\,BH}$. Calculations are carried out for the copper screen with a diameter of 30 mm, by the thickness of 0.2 mm. From the figure one can see that the shielding shell in the mode/conditions of protection from outside interferences $(A_{э\,BH})$ has higher shielding properties, than in the mode/conditions of protection from interferences of bilateral circuits $(A_э)$.

Excess caused by attenuation length of the shadowing of longitudinal currents is approximately 2-2.5 Np in all frequency band. At high frequencies value A_z is determined only by the external inductance of circuit "shell-ground".

With an increase in the frequency, the shielding characteristics $A_{э\,BH}$ and $A_э$ increase, whereas A_z at high frequencies has slowly dropped/collapsible character. Calculations show that approximately to the frequencies of 15-20 kHz prevails the attenuation of shadowing because of longitudinal currents (A_z), a more than it manifests itself

the effect of transverse eddy currents $(A_э)$.

Thus, knowing the effectiveness of screen from interferences of bilateral circuits $(A_э=A_п+A_о)$, it is possible by means of the addition of value $A_г$ to determine the characteristics of this screen in the mode/conditions of protection from outside interferences $(A_{э\,вн}=A_э+A_г)$.

2.7. Special feature/peculiarities of the shadowing of coaxial cables.

In coaxial cables the screens are applied for the protection of circuits from mutual and outside interferences. Shadowing makes it possible to conclude several coaxial lines to common/general/total outer covering and to realize a transmission along single-cable system. Multichannel communicating systems and the telecasts of direct/straight (A-B) and opposite (B-A) directions are placed in one cable.

The screening effect of coaxial cable is completely caused by the structural/design and electrical data of the

external wire of cable. External wire is the return conductor of the circuit of transmission and performs the role of the electromagnetic screen, which shields coaxial circuit from interferences. For this very reason the external wire of coaxial cable is designed both for the passage of communication signals along cable and for the provision for the required norms cf interference shielding.

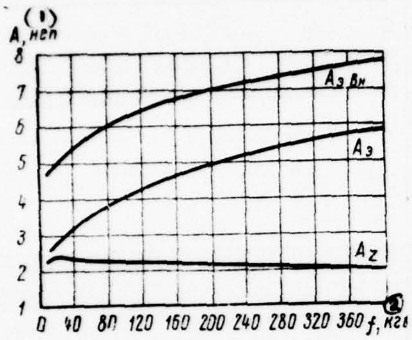

Fig. 2.9. Screening effect of shell in conditions of protection from outside interferences $(A_{э\,вн})$ **and in mode/conditions of protection from interferences** $(A_э)$

Key: (1). Np. (2). f, kHz.

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During transmission on to coaxial cables least shielded from noise is the low frequency spectrum of the order to 50-60 kHz, and in the range of high frequencies, the protection of circuits from interferences is very great. In bilateral circuits, on the contrary, with an increase in the frequency the mutual interaction between circuits grow/rises and protection against outside interferences falls.

The character of the frequency dependence of noise current in coaxial and bilateral circuits is given in Fig. 2.10. These phenomena in coaxial circuits are explained by the fact that due to proximity effect the current density in the external wire of coaxial cable increases towards its internal surface. With an increase of current frequency, has a tendency to be concentrated on the internal surface of external wire, and on its external surface tightly decreases (Fig. 2.11). Therefore with an increase in the frequency, decreases the strength of field E_z on the external surface of wire and grow/rises the effect of the self-protection of coaxial cable.

At the very high frequencies when entire current is concentrated within coaxial cable, the strength of field of outside cable approaches zero, screening effect reaches maximum, and the interaction between circuits theoretically is absent.

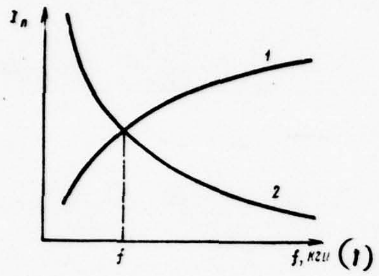
In accordance with determination by datum in Section 1.1, the screening constant is determined by the expression

$$S = \frac{E^э}{E} = \frac{H^э}{H}, \qquad (2.32)$$

where $E^э$ and $H^э$— are strengths of field with the presence

of screen; E and H - in the absence of screen.

In connection with coaxial cable, taking into account that the thickness of external conductor (screen) is insignificant in comparison with the common/general/total section of cable, value $E^э(H^э)$ and E (H) it is possible to replace with strength by the external and internal surfaces of external wire - the screen of cable.



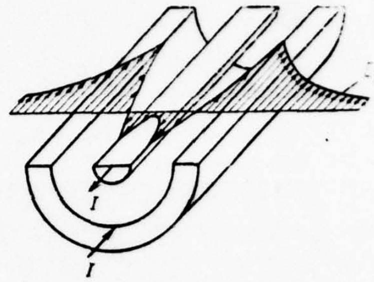


Fig. 2.11.

Fig. 2.10. Frequency dependence of mixing effect in coaxial (2) and symmetrical (1) cables.

Fig. 2.11. Longitudinal component of electric field in thickness of external wire (screen) of coaxial cable.

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In this case, it is most expedient to operate with coaxial components electric field E_z. Then the screening constant of coaxial cable is expressed by the relationship/ratio

$$S = \frac{E_z\ (\text{при}\ r+t)}{E_z\ (\text{при}\ r_э)}. \qquad (2.33)$$

Key: (1). with.

Values E_z of coaxial cable are determined with the aid of the equations of electrodynamics in cylindrical coordinate

system. The longitudinal component of electric field at any point of the section cf external wire - the screen of coaxial cable is determined by formula [5]

$$E_z = Z_м \frac{I}{2\pi\sqrt{r_э r}} \frac{\operatorname{ch}[\kappa(r_э + t - r)]}{\operatorname{sh} \kappa t}, \qquad (2.34)$$

where $Z_м = \sqrt{i\omega\mu/\sigma}$ — is wave impedance of metal - screen; $\kappa = \sqrt{i\omega\mu\sigma}$ — - the coefficient of eddy currents; $r_э$ — is an inside radius of screen; t is thickness of screen; I - the current, which takes place on external wire; r is the current radius.

Values E_z when $r_э$ and $r_э + t$ are determined by the following formulas:

$$\left.\begin{aligned} E_z &= Z_м \frac{I}{2\pi r_э} \operatorname{ch} \kappa t \quad \text{при (1)} \quad r = r_э \\ E_z &= Z_м \frac{I}{2\pi\sqrt{(r_э + t) r_э}} \cdot \frac{1}{\operatorname{sh} \kappa t} \quad \text{при (1)} \quad r = r_э + t \end{aligned}\right\}. \qquad (2.35)$$

Key: (1). with.

Respectively the screening constant of coaxial cable will be expressed as follows:

$$S = \frac{E_z(\text{при (1)}\ r_э + t)}{E_z(\text{при}\ r_э)} = \frac{1}{\operatorname{ch} \kappa t}. \qquad (2.36)$$

Key: (1). with. It is here taken into account, that $\frac{r_э + t}{r_э} \approx 1.$

The screen attenuation of coaxial cable will be

$$A_э = \ln \left| \frac{1}{S} \right| = \ln |\operatorname{ch} \kappa t|. \qquad (2.37)$$

In the range of high frequencies, when kt $\gg$ 3, it is possible to use the entreated formula

$$A_э = |\kappa t| = |\sqrt{i \omega \mu \sigma}\, t|. \qquad (2.38)$$

Comparing the obtained expressions S and $A_э$ for the calculation of the shielding properties of coaxial cables with analogous expressions for calculation S and $A_э$ of balanced cables, it can be noted that the shadowing of bilateral circuits is determined by total screening effect of absorption (S_n) and of the shadowing of reflection (S_0). In coaxial circuits operates only the shadowing of absorption $|S_n = 1/\operatorname{ch} \kappa t|$.

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This is caused by the facts that in coaxial cables the current directly passes along screen (to external wire), and in bilateral circuits screen is located in the sphere of influence of electromagnetic field, created by the current, which takes place on the shielded circuit. Therefore action

of the screen, utilized in the mode/conditions of the work of coaxial cable, gives smaller effect than in bilateral circuit. At the same material of screen, its thickness and current frequency, screening effect in symmetrical and coaxial cables differs by attenuation length of reflection (A_0). However, this not that means that the mixing effect in the shielded bilateral circuits is less than in coaxial. On the contrary, the interference shielding of coaxial cables is above, since the field of the interferences of the balanced cables is substantially more than coaxial ones. Therefore, although screening effect of balanced cables is greater than coaxial, their interference shielding is considerably below.

Table 2.2 gives given data of the attenuations of the shadowing of coaxial cables in the range of the frequencies of 30-550 kHz with thickness of boundary of screen 0.1 mm. The attenuation of shadowing increases from frequency. The best effect gives the steel screen, worst, i.e., lead. Moreover, if of nonmagnetic screens with an increase of frequency the attenuation of shadowing evenly grow/rises, then in steel screen this growth is slower.

Table 2.2. Screening effect of the single-layer screens of coaxial cable ($A_э$), Np.

(1) f, кгц	(2) Медь	(3) Алюминий	(4) Свинец	(5) Сталь
30	0,25	0,15	0,02	3,44
60	0,46	0,29	0,04	3,99
100	0,71	0,46	0,07	5,54
310	1,67	1,15	0,20	6,24
550	2,45	1,73	0,35	6,83

Key: (1). f, kHz. (2). Copper. (3). Aluminum. (4). Lead. (5). Steel.

Chapter 3.

MULTILAYER COMBINED SCREENS.

3.1. Operating principle of multilayer screens.

The electromagnetic screens of the combined multilayer construction are applied when is necessary the high screening effect. Screens consist predominantly of the consecutively alternating nonmagnetic (copper, aluminum) and magnetic (steel, Permalloy) layers. The special feature/peculiarity of such multilayer screens is the high shielding effectiveness and comparatively low losses of energy in screen. These advantages are explained as follows. In the examination of the uniform screens of electromagnetic action, it was establish/installed that screening effect is determined by the combined action of the shadowing of absorption $S_п$ and of the shadowing of reflection S_0 on boundaries dielectric - metal - dielectric. The effect of reflection is caused by the nonconformity of the wave characteristics of the joining mediums ($Z_д$ and $Z_м$), and the

greater this nonconformity, that the more screening effect. In this case energy of interferences, encountering in its path this electrical nonconformity $(Z_{\text{д}} \neq Z_{\text{м}})$, partially it is reflected and only partially it passes into the shielded space. This phenomenon will serve as initial torque/moment for construction and applying the multilayer combined screens. In the multilayer screen, comprised of metals with different wave impedance $\dot{Z}_{\text{м}}$, operates the whole system of such multiple reflections from the boundaries of electrical nonconformities $(Z_{\text{м}1} \neq Z_{\text{м}2} \neq Z_{\text{м}3} \neq \dot{Z}_{\text{м}4}$ so forth). Therefore the screen, which consists of several thin layers of different metals, will possess the larger effectiveness of shadowing in comparison with the uniform screen of equivalent thickness.

As can be seen from Fig. 3.1, in single-layer screen there are two boundaries (air - metal and metal - air) of reflection, but in the three-layered of such boundaries, four, are added an additional two boundaries between different metallic layers.

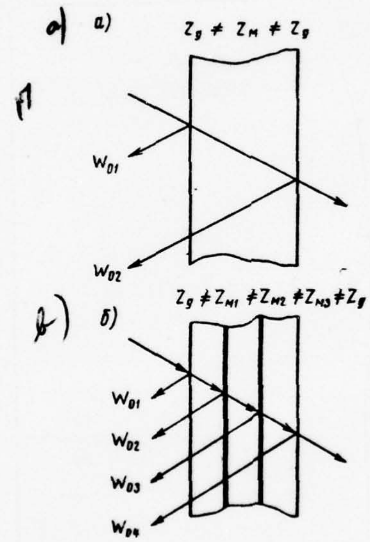

Fig. 3.1. Effect of reflection in single-layer (a) and three-layered (b) screens.

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Essential are the order of banding, their electrical combination, the relationship/ratio of thickness of the layer, and also place with respect to the affecting circuit. Thus, for instance, combination steel-copper-aluminum gives noticeably smaller effect than copper-steel-aluminum. If exterior layers of multilayer screen are made from nonmagnetic materials, then losses in it are comparatively small.

It would be possible to solve the problem of the multilayer combined screens on the basis of the solution to differential equations for each layer and the determinations of integration constants from the boundary continuity conditions of the corresponding components of electromagnetic field. However, in connection with the large number of layers (three it is more), this is very cumbersome and it is connected with indirect conversions and computations. For convenience we will use wave principles taking into account the incident and reflected waves. In this case the incident wave corresponds mainly to the field of the source of interferences, and the wave reflected - to a field of the reaction of screen. The examination of the phenomena of shadowing by "wave" method substantially simplifies the solution of problem and gives the demonstrative

representation of the essence of the processes of shadowing, especially in connection with multilayer screens.

3.2. Shielding characteristics of two-layered screens.

According to wave method the physical essence of shadowing lies in the fact that electromagnetic energy, after achieving screen, partially is passed through it, somewhat attenuating in this case, and partially it is reflected in the first boundary dielectric-screen because of the nonconformity of the wave characteristics of dielectric and metal. In the second boundary (screen-dielectric) the part of the energy again is reflected and only the part of it passes further. The same is repeated on the subsequent boundaries of multilayer screens. This process continues to the complete attenuation of the refracted and reflected waves.

Figures 3.2 shows the two-layered screen which has thickness of the layer t_1 and t_2 and the coefficients of eddy currents k_1 and k_2. The phenomenon of the passage of the electromagnetic energy through the screen according to

"wave" method is represented in the form of the infinite series of the component incident, reflected and refracted waves. For the solution to stated problem, one should examine three groups of electromagnetic fields.

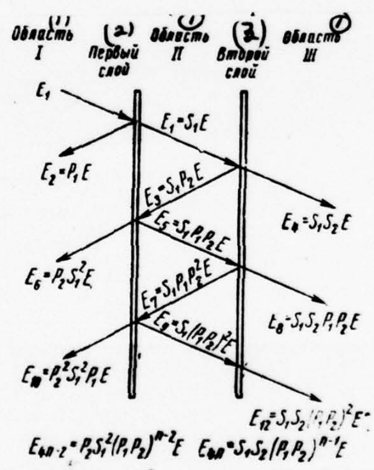

Fig. 3.2. Electromagnetic processes in twc-layered screen.

Key: (1). Range. (2). First layer. (3). Second layer.

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Electromagnetic waves to the left of screen (range I). In this range operates the incident wave of the source of interferences E and the sum of the waves reflected because of the reaction of screen (E_2, E_6. ..., $E_{4\eta-2}$). The addition of fields in range I will make it possible to determine the reaction of screen P.

The electromagnetic waves between screens (range II). Here acts the whole system of the repeatedly waves reflected from both words of screen (E_1, E_3, ..., $E_{2\eta-1}$).

Electromagnetic waves to the right of screen (range III). Here are summarized the waves, passed through the screen (E_4, E_8, ..., $E_{4\eta}$). Screening constant is determined in the form of the ratio of the fields, passed through the screen into range III, to the field of the source of interferences E.

Reflection process and refraction of electromagnetic waves can be presented in the following form. On the surface of the first layer of screen, falls the wave of the source of interferences E. The part of the energy will

be reflected back into range I and it can be expressed through the coefficient of the reaction of the first layer of screen P_1 in the form $E_2 = P_1E$. The part of the energy passes into range II, after decreasing proportional to the screening constant of the first layer of screen S_1, i.e., $E_1 = S_1 = S_1E$. This field, after entering to the surface of the second layer, partially will be reflected $E_3 = E_1P_2 = S_1P_2E$, and partially passes into the shielded space - range III. Passed into range III field will be determined in the form $E_4 = S_2E_1 = S_1S_2E$, where S_2 and P_2 are screening constants and reaction of the second layer of screen.

Wave E_3, being reflected conversely, it will cause in range I wave of reaction $E_6 = E_3S_1 = S_1^2 P_2E$ and in range II the incident wave $E_5 = E_3P_1 = S_1P_1P_2E$. This wave partially passes into range III in the form $E_8 = E_5S_2 = S_1S_2P_1P_2E$, and partially will be reflected (E_7). Wave E_7 will cause the incident, reflected and refracted waves, and so this process can be continued to infinity. It is natural that all the entering components of this series will have continually decreasing amplitude. As a result it is possible to write that in range I operates the field of the reaction of screen, equal to the sum of the waves

of the type E_{4n-2} REFLECTED:

$$E^{o} = P_{12}E = \sum_{n=1}^{\infty} E_{4n-2} = P_1E + \sum_{n=1}^{\infty} P_2 S_1^2 (P_1P_2)^{n-2} E.$$

Summarizing this series, we will obtain

$$E^{o} = P_{12}E = E\left[P_1 + \frac{P_2S_1^2}{1-P_1P_2}\right]. \qquad (3.1)$$

Hence the coefficient of the reaction of two-layered screen can be expressed by the coefficients of the reaction of separate layers (P_1 and P_2):

$$P_{12} = P_1 + \frac{P_2S_1^2}{1-P_1P_2}. \qquad (3.2)$$

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In range III - in the shielded space - will operate a whole series of passed through the screen fields of the type E_{4n}:

$$E^{э} = S_{12}E = \sum_{n=1}^{\infty} S_1S_2 (P_1P_2)^{n-1} E = S_1S_2 \frac{1}{1-P_1P_2} E. \qquad (3.3)$$

Hence the screening constant of two-layered screen will be determined in the form

$$S_{12} = \frac{S_1S_2}{1-P_1P_2}. \qquad (3.4)$$

utilizing formulas of calculation S and P of uniform screens [formula (2.6) and (2.8)] and after substituting

them into expressions for P_{12} and S_{12}, we will obtain:

$$S_{12}=\frac{1}{\operatorname{ch}\kappa_1 t_1 \operatorname{ch}\kappa_2 t_2}\times$$

$$\times\frac{1}{1+\frac{1}{2}\left(N_1+\frac{1}{N_1}\right)\operatorname{th}\kappa_1 t_1+\frac{1}{2}\left(N_2+\frac{1}{N_3}\right)\operatorname{th}\kappa_2 t_2+\frac{1}{2}\left(N_3+\frac{1}{N_3}\right)\operatorname{th}\kappa_1 t_1 \operatorname{th}\kappa_2 t_2}, \quad (3.5)$$

$$P_{12}=\frac{\frac{1}{2}\left(N_1-\frac{1}{N_1}\right)\operatorname{th}\kappa_1 t_1+\frac{1}{2}\left(N_2-\frac{1}{N_2}\right)\operatorname{th}\kappa_2 t_2+\frac{1}{2}\left(\frac{1}{N_3}-N_3\right)\operatorname{th}\kappa_1 t_1 \operatorname{th}\kappa_2 t_2}{1+\frac{1}{2}\left(N_1+\frac{1}{N_1}\right)\operatorname{th}\kappa_1 t_1+\frac{1}{2}\left(N_2+\frac{1}{N_2}\right)\operatorname{th}\kappa_2 t_2+\frac{1}{2}\left(N_3+\frac{1}{N_3}\right)\operatorname{th}\kappa_1 t_1 \operatorname{th}\kappa_2 t_2}, \quad (3.6)$$

where k_1t_1 and k_2t_2 - the parameters of the first and second layers of screen; $N_1 = Z_Д/Z_{M1}$; $N_2 = Z_Д/Z_{M2}$; $N_3 = Z_Д/Z_{M3}$ - the relationship/ratio of wave impedance.

3.3. Shielding characteristics of multilayer screens.

The shielding property of screen, which consists of three and larger number of layers, they can be determined

with the consecutive substitution of values on the basis of the initial positions, examined above for a two-layered screen. Utilizing formulas of the calculation of two-layered screens, we consecutively lead multilayer screen to two-layered and we determine its characteristic (S and P). Let, for example, it is necessary to determine characteristics (S and P). Let, for example, it is necessary to determine the characteristics of four-layer screen. First we lead two layers to one two-layered screen and find its S and P. Then we add the third layer and, counting the first of two layers for one, we find through formula (3.4) the total shielding characteristics of three-layered screen. Finally, we sum three-layered screen with the fourth layer and with the aid cf this same formula it is obtained the unknown shielding characteristics S and P (total) of four-layer screen. This method of consecutive substitution it is possible tc develop to how welcome quantity of layers in the combined multilayer screens.

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Using in an indicated manner, let us examine the shielding characteristics of the three-layered screen, which has use

along with the screens of bimetallic construction. Let us assume that S_1, S_2, S_3 and P_1, P_2, P_3 - screening constants and the coefficients of the reaction of uniform screens 1, 2, 3, consisted of intc common/general/total three-layered screen. Parameters S and P of two layers (2 + 3) according to formulas (3.2) and (3.4): $S_{23} = S_2S_3/1-P_2P_3$, $P_{23} = P_2 + P_3S_2^2/1-P_2P_3$.

Accepting of these of two layers as one, we sum screen (2 + 3) with screen 1: $S_{123} = S_{23}S_1/1-P_{23}P_1$; $P_{123} = P_1 + P_{23}S_1^2/1-P_{23}P_1$. Substituting here values S_{23} and P_{23}, we will obtain that the screening constant of three-layered screen is equal to

$$S_{123}=\frac{S_1S_2S_3}{(1-P_1P_2)(1-P_2P_3)-P_1P_3S_2^2}, \quad (3.15)$$

and the coefficient of the reaction of the three-layered screen

$$P_{123}=P_1+\frac{P_2(1-P_2P_3)S_1^2+P_3S_1^2S_2^2}{(1-P_1P_2)(1-P_2P_3)-P_1P_3S_2^2}. \quad (3.16)$$

Analogous expressions for S_{123} and P_{123} are obtained during the solution to equations for three-layered screens by "wave" method by means of the addition of the incident and reflected waves.

Bearing in mind that the term, which contains the fourth degree of the coefficient of screening is extremely small, it is possible the coefficient of the reaction of screen to present in the following form:

$$P_{123} = P_1 + \frac{P_3(1 - P_2P_3)\,S_1^2}{(1 - P_1P_2)(1 - P_2P_3) - P_1P_3S_2^2}. \quad (3.17)$$

Widest application have three-layered screens with identical skins ($S_1 = S_3$ and $P_1 = P_3$). For this case of formula, they take the form:

$$S_{121} = \frac{S_1^2\,S_2}{(1 - P_1P_2)^2 - (P_1S_2)^2}; \quad P_{121} = P_1 + \frac{P_2(1 - P_1P_2)S_1^2}{(1 - P_1P_2)^2 - (P_1S_2)^2}.$$

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Tables 3.1. Screen attenuation of two-layered screens.

TABLE 3.1

f, гц	Медь—сталь (1)			(2) Алюминий—свинец			(3) Свинец—сталь			(4) Алюминий—сталь		
	$A_{п12}$	$A_{о12}$	$A_{э12}$	$A_{п12}$	$A_{о12}$	$A_{э12}$	$A_{п12}$	$A_{о12}$	$A_{э12}$	$A_{п12}$	$A_{о12}$	$A_{э12}$
(5) При магнитном поле $\left(Z_д=Z_д^H\right)$												
10^3	0	0,575	0,575	0	0,138	0,138	0	0,45	0,45	0	0,575	0,575
10^4	0,23	1,82	2,05	0	0,928	0,928	0,23	0,755	0,985	0,23	1,26	1,49
10^5	0,975	3,52	4,495	0,046	2,76	2,806	0,966	1,58	2,546	0,965	3,05	4,015
10^6	5,42	4,91	10,33	0,391	4,71	5,101	4,61	3,22	7,83	5,06	4,7	9,76
10^7	20,3	5,89	26,19	3,55	5,85	9,4	16,8	4,62	21,42	19,2	5,55	24,75
10^8	68,6	7,0	75,6	14,4	7,00	21,4	55,4	5,82	61,22	65	6,75	71,75
(6) При электрическом поле $\left(Z_д=Z_д^E\right)$												
10^3	0	29,4	29,4	0	28,8	28,8	0	27,6	27,6	0	28,8	28,8
10^4	0,23	27,0	27,23	0	26,6	26,6	0,23	25,4	25,63	0,23	26,6	26,83
10^5	0,975	24,7	25,675	0,046	24,2	24,24	0,966	22,6	23,56	0,965	24,2	26,16
10^6	5,42	22,0	27,42	0,39	21,6	21,99	4,61	20	24,61	5,06	21,8	26,86
10^7	20,3	18,2	38,5	3,55	18,2	21,75	16,8	17,1	33,9	19,2	17,85	37,05
10^8	68,6	14,7	83,3	14,4	14,7	29,1	55,4	13,5	68,9	65	14,5	79,5
(7) При плоской волне $\left(Z_д=Z_д^{EH}=Z_0\right)$												
10^3	0	14,0	14,0	0	13,45	13,45	0	12,3	12,3	0	13,5	13,5
10^4	0,23	14,0	14,23	0	13,4	13,4	0,23	12,28	12,51	0,23	13,5	13,73
10^5	0,975	13,85	14,825	0,048	13,3	13,34	0,966	11,89	12,856	0,965	13,4	14,365
10^6	5,42	13,2	18,62	0,391	13,15	13,55	4,61	11,5	16,11	5,06	13,2	18,26
10^7	20,3	12,0	32,3	3,55	12,0	15,55	16,8	11,0	27,8	19,2	11,7	30,9
10^8	68,6	10,82	79,42	14,4	10,9	25,3	55,4	9,65	65,05	65,0	10,6	75,7

Key: (1). Copper-steel. (2). Aluminum-lead. (3). Lead-steel. (4). Aluminum-steel. (5). In magnetic field. (6). In electric field. (7). With plane wave.

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3.4. Effectiveness of multilayer screens in different fields.

Let us examine the action of two-layered screens during the different combination of metals (copper, aluminum, steel, lead) relative to electrical, magnetic and electromagnetic fields. Thickness of the layer of screens 0.1 mm. Frequency band from 10^3 to 10^8 Hz. The calculation of the attenuation of shadowing is conducted according to formulas (1.25) and (3.12). Wave impedance is determined from the formulas: $Z_{д}^{H}=i\omega\mu r$ (dielectric of relatively magnetic wave); $\dot{Z}_{д}^{E}=1/i\omega\varepsilon r$ (dielectric of relatively electrical wave); $Z_{д}^{EH}=Z_0\sqrt{\mu/\varepsilon}$ (dielectric of relatively plane wave); $Z_{м}=\sqrt{i\omega\mu/\sigma}$ (metal for any wave).

Table 3.1 gives corrected values of the screen attenuation of the absorption ($A_{\Pi 12}$), of the screen attenuation of reflection (A_{012}) and of the resulting screen attenuation ($A_{Э12} = A_{\Pi 12} + A_{012}$) for two-layered screens of the type" copper-steel", aluminum-steel and aluminum-lead under the influence of the magnetic ($Z^{H}_{Д}$), electrical ($Z^{E}_{Д}$) and flat/plane electromagnetic (Z_0) of waves. The attenuation of absorption ($A_{\Pi 12}$) does not depend on transmission mode and in all cases sharply increases with an increase of frequency. The greatest effect on the attenuation of absorption is reached because of steel layer in combination copper-steel and aluminum-steel. Most bad combination aluminum-lead.

The attenuation of reflection (A_{012}) for different transmission modes has the different frequency dependence: for an electrical wave ($A^{E}_{0\,12}$) - with an increase of frequency it falls from infinity, for magnetic ($A^{H}_{0\,12}$) - it increases from zero, and for plane electromagnetic wave ($A^{EH}_{0\,12}$) - has at first constant value, and then somewhat decreases.

The screen attenuation of two-layered (copper - steel) screen with magnetic, electrical and plane waves is shown to Fig. 3.3.

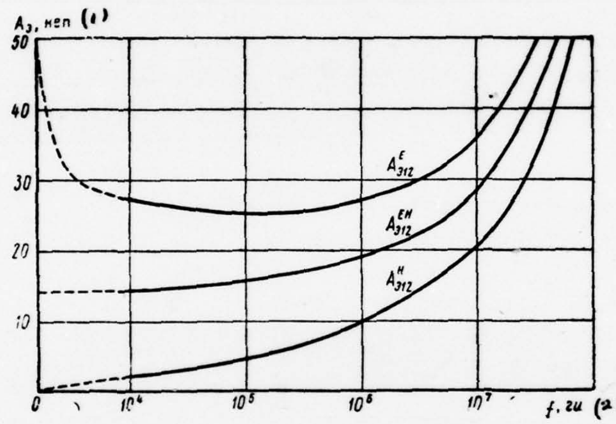

Fig. 3.3. Screen attenuation of two-layered screen (copper-steel) with magnetic ($A^H_{э12}$), electrical ($A^E_{э12}$) and plane ($A^{EH}_{э12}$) waves.

Key: (1). Np. (2). Hz.

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For a magnetic field with an increase of frequency $A^{H}_{э12}$, it increases from zero to large values. For the electric field $A^{E}_{э12}$, it falls at first from infinity, and then sharply increases, having a minimum at frequencies 10^5-10^7 Hz. The attenuation of the shadowing of plane electromagnetic wave in the range to 10^5 Hz has constant value (13 Np), and then substantially grow/rises.

In absolute value best of all the combination of nonmagnetic (copper-aluminum) and magnetic (steel) layers. So, at frequency 10^6 Hz for a magnetic wave screen copper-steel gives attenuation 10.33 Np, aluminum-steel 9.76 Np, lead-steel 7.83 Np and combination of nonmagnetic metals aluminum-lead - altogether only 5.1 Np.

From the preceding information it is evident that most susceptible is the effectiveness of screens relatively magnetic field, and therefore during screens them it is necessary first of all to design, on the basis of magnetic effect. Taking into account this, let us examine in more detail the action of three-layered screen of relatively magnetic effect for the different combinations of metals (copper, steel, of aluminum and lead). The results of the calculation of the screen attenuation of three-layered

screens are given to Fig. 3.4. Thickness of the layer is accepted equal to 0.1 mm. Skins, on the basis of the requirement for the achievement of minimum losses and best screening effect, are accepted of nonmagnetic materials. The best results gives the screen, comprised of nonmagnetic and magnetic materials. $A_э$ screen of the type "copper" at the frequency of 150 kgh is equal to 8 Np. The application/use of steel with high magnetic permeability (μ = 200) makes it possible to obtain at frequency 150 kHz supplementary screen attenuation in 1 Np. Good results gives a screen of the type "aluminum". The most unfavorable combination is obtained in constructions lead-steel-lead. This screen has the screen attenuation of the order altogether only 4 Np.

The considerations given above in connection with two-layered screens about the effectiveness of the combination of different layers in wide frequency spectrum are valid also for three and larger number of layers of the combined screens.

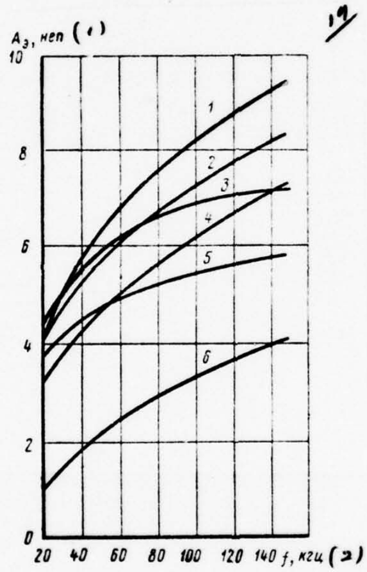

Fig. 3.4. Frequency dependence of the screen attenuation of the three-layered screens:

1 - copper-steel-copper (μ = 200); 2 - copper-steel-copper

(μ = 100); 3 - aluminum-steel-aluminum; 4 - copper-lead-copper; 5 - copper-aluminum-copper; 6 - lead-steel-lead.

Key: (1). Np. (2). kHz.

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After establishing that the most advantageous combination cf materials for the creation of multilayer screens is copper and steel, it is expedient to examine the effectiveness of an increase of the number of layers in the combined screens. Figures 3.5 gives the results of measurements of the three-, by four and five-layer screens of cylindrical construction made of copper with a thickness of 0.08 mm will become - 0.1 mm. Here for a comparison given data of single-layer copper screen (1). From curve/graph it is evident that $A_э$ five-layer screen (4) of the type copper-steel-copper-steel-copper on 2-3 Np is greater than three-layered screen (2) (copper-steel-copper). The screen attenuation of four-layer screen (3) differs from $A_э$ three-layered by 1 Np. In absolute value at frequency 130 kHz, single-layer screen gives 3.5 Np, three-layered,

i.e., 6.7 Np, and five-layer - about 10 Np.

3.5. Physical processes in compound/composite screens.

In accordance with foregoing the screen attenuation of two-layered screen can be determined by the formula

$$A_{\text{э}12} = \ln\left|\frac{1 - P_1P_2}{S_1 S_2}\right| = A_{\text{п}12} + A_{\text{о}12}, \qquad (3.18)$$

where, in turn,

$$A_{\text{п}12} = \ln\left|\frac{1}{S_{\text{п}1} S_{\text{п}2}}\right| = \ln\left|\operatorname{ch}\kappa_1 t_1 \operatorname{ch}\kappa_2 t_2\right|, \qquad (3.19)$$

$$A_{\text{о}12} = \ln\left|\frac{1 - P_1P_2}{S_{\text{о}1} S_{\text{о}2}}\right| = \ln\left|1 + \frac{1}{2}\left(N_1 + \frac{1}{N_1}\right)\operatorname{th}\kappa_1 t_1 + \right.$$
$$\left. + \frac{1}{2}\left(N_2 + \frac{1}{N_2}\right)\operatorname{th}\kappa_2 t_2 + \frac{1}{2}\left(N_3 + \frac{1}{N_3}\right)\operatorname{th}\kappa_1 t_1 \operatorname{th}\kappa_2 t_2\right|. \qquad (3.20)$$

Analyzing the obtained results, it can be noted that according to its structure of the formula of the calculation of the shielding properties of compound/composite screen are analogous to the formulas of the calculation of the shadowing of single-layer screens. Screen attenuation ($A_{\text{э}12}$) consists of screen of attenuation of absorption of metal ($A_{\text{п}12}$)

and the screen attenuation of **reflection** (A_{o12}). **The** screen attenuation of absorption **includes the product** of the hyperbolic cosines, corresponding parameters (kt) of the first and second layers of screen and it is equal to the sum of the attenuations of the absorption of both layers of screen.

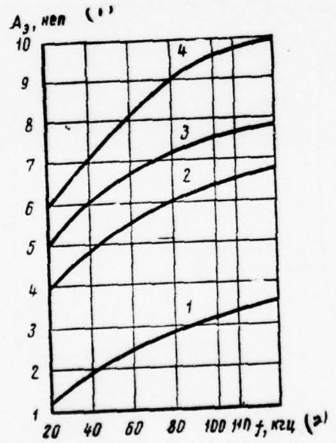

Fig. 3.5. Results of the measurement of the screen attenuation of the different multilayer screens: 1 - single-layer (copper); 2 - three-layered (copper-steel copper); 3 - four-layer (copper-steel-steel-copper); 4 -

five-layer (copper-steel-copper-steel-copper).

Key: (1). Np. (2). kHz.

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The screen attenuation of reflection contains several components which are caused by reflections on the appropriate interfaces:

$$\frac{1}{2}\left(N_1+\frac{1}{N_1}\right)\operatorname{th}\kappa_1 t_1 \text{ — диэлектрик — I слой экрана;} \quad (1)$$

$$\frac{1}{2}\left(N_2+\frac{1}{N_2}\right)\operatorname{th}\kappa_2 t_2 \text{ — II слой экрана — диэлектрик;} \quad (2)$$

$$\frac{1}{2}\left(N_3+\frac{1}{N_3}\right)\operatorname{th}\kappa_1 t_1 \operatorname{th}\kappa_2 t_2 \text{ — I слой экрана — II слой экрана.} \quad (3)$$

Key: (1). Dielectric - I layer of screen. (2). II Layer of screen - dielectric. (3). I layer of screen is II layer of screen.

The absolute values of the indicated expressions are caused by the relationship/ratios of the wave impedance of the joining mediums. The greater its nonconformity, the greater the value of N above screening effect. Thus, for

instance, role and the specific significance of different couplings in common/general/total screening effect are characterized for the screen of construction copper-steel by the thickness of the layer on 0.1 mm at the frequency of 100 kgh of relatively magnetic field as follows: $Z_{Д}^{H}$ = $13.8 \cdot 10^{-3}$ ohm, $Z_{меди}$ = $0.12 \cdot 10^{-3}$ ohm, $Z_{стали}$ = $3.3 \cdot 10^{-3}$ ohm.

Respectively N = 115, $1/N_1$ = 0.0087;

$$N_2 = 4{,}2,\ \frac{1}{N_2} = 0{,}24;$$
$$N_3 = 0{,}036,\ \frac{1}{N_3} = 27{,}5.$$

Then the attenuation of reflection on the appropriate boundaries will be: 3.7 Np-air-copper, 1.1 Np-air-steel, 2.2 Np-copper-steel. All couplings together (air-copper-steel-air) give 3.9 Np. Consequently, the greatest screening effect gives boundary dielectric-copper. The effect of boundary nonconformity dielectric-steel is very small. Reflection at a boundary of different metals gives somewhat larger effect than on boundary of dielectric-steel. Furthermore, with one layer (t_2 = 0) Analyzing formula of the shadowing of compound/composite screens assumes the form, characteristic to the single-layer screens: $A_{Э12}$ = $A_Э$ = ln | ch kt [1 + 1/2 (N + 1/n) x th kt]. If both layers have identical

thickness and are made from uniform metal ($k_1t_1 = k_2t_2 = kt$), then

$$A_{э12} = \ln\left|\operatorname{ch}^2 \varkappa t\left[1+\left(N+\frac{1}{N}\right)\operatorname{th}\varkappa t+\operatorname{th}^2\varkappa t\right]\right| =$$
$$= \ln\left|\operatorname{ch} 2\varkappa t\left[1+\frac{1}{2}\left(N+\frac{1}{N}\right)\operatorname{th} 2\varkappa t\right]\right|, \quad (3.21)$$

i.e. the two-layered screen, made from uniform metals ($t_1 + t_2$), gives the same effect, as the single-layer screen of the doubled thickness 2t [see formula (2.6)].

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The screen attenuation of the two-layered screen $A_{э12}$ is expressed as the attenuation of absorption $A_{П12}$ and attenuation of reflection A_{o12} of this screen. The shielding characteristics of the two-layered screen $A_{э12}$ also can be expressed by the shielding characteristics of the single-layer screens, entering this compound/composite screen ($A_{э1}$ and $A_{э2}$). Actually, since $S_{12} = S_1S_2/1 - P_1P_2$, then $A_{э12}$ $= \ln \left| 1-p_1p_2/S_1S_2 \right| = A_{э1} + A_{э2} + A_p$, where

$$
\left.\begin{aligned}
A_{э1} &= \ln\left|\frac{1}{S_1}\right| = \ln\left|\operatorname{ch}\kappa_1 t_1\left[1+\frac{1}{2}\left(N_1+\frac{1}{N_1}\right)\operatorname{th}\kappa_1 t_1\right]\right| \\
A_{э2} &= \ln\left|\frac{1}{S_2}\right| = \ln\left|\operatorname{ch}\kappa_2 t_2\left[1+\frac{1}{2}\left(N_2+\frac{1}{N_2}\right)\operatorname{th}\kappa_2 t_2\right]\right|
\end{aligned}\right\}. \quad (3.22)
$$

Parameter A_p of this attenuation of interaction (reaction) between the layers of screen. It is characterized by the effectiveness of the combination of different metals in compound/composite screen:

$$
A_p = \ln|1 - P_1 P_2| =
$$

$$
= \ln\left|\frac{1+\frac{1}{2}\left(N_1+\frac{1}{N_1}\right)\operatorname{th}\kappa_1 t_1+\frac{1}{2}\left(N_2+\frac{1}{N_2}\right)\operatorname{th}\kappa_2 t_2+\frac{1}{2}\left(N_3+\frac{1}{N_3}\right)\operatorname{th}\kappa_1 t_1\operatorname{th}\kappa_2 t_2}{\left[1+\frac{1}{2}\left(N_1+\frac{1}{N_1}\right)\operatorname{th}\kappa_1 t_1\right]\left[1+\frac{1}{2}\left(N_2+\frac{1}{N_2}\right)\operatorname{th}\kappa_2 t_2\right]}\right|. \quad (3.23)
$$

Value of P is given in chapter 2.

3.6. Multilayer screens with dielectric separators.

Is of practical interest the question concerning effectiveness and advisability of equipment/device of

dielectric liners (paper, plastic) or of air gaps between the metallic layers of the combined screen. Let us examine the simplest case of two-layered metal screen with the dielectric layer between them. For investigation let us use the formula of three-layered screen [formula (3.15)]:

$$S = \frac{S_1 S_2 S_3}{(1 - P_1 P_2)(1 - P_2 P_3) - n P_1 P_3 S_2^2}. \qquad (3.24)$$

Coefficient n considers the effect of the wall thicknesses of screen. For the cylindrical screen $n = (R_1/R_3)^2$, for the spherical screen $n = (R_1/R_3)^3$ (R_1 is a outside diameter of I layer, R_3 - the inner diameter of III layer).

For the thin-walled screens, examined earlier, it is accepted as $n \approx 1$.

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In order to determine the screening constant of two-layered screen with layer, it is necessary into formula for S to substitute the shielding parameters of dielectric layer (S_2 and P_2). For dielectric $S_2 = 1$ and $P_2 = 0$. Then

$$S = \frac{S_1 S_3}{1 - n P_1 P_3}. \qquad (3.25)$$

The screen attenuation of this screen will be $A_э = \ln \left| 1/S \right| = A_{э1} + A_{э3} + A_p$, where $A_{э1} = \ln \left| \frac{1}{S_1} \right|$ - screen attenuation I of metallic layer; $A_{э3} = \ln \left| \frac{1}{S_3} \right|$ - screen attenuation II of metallic layer; $A_p = \ln \left| 1 - nP_1P_3 \right|$ - Attenuation of the interaction (reaction) of the layers of the combined screen.

Comparing the obtained result with the formulas of the calculation of usual two-layered screens (3.23), we see that the difference is only in the parameter A_p. In the two-layered screen $A_p = \ln \left| 1 - P_1P_2 \right|$.

For determining the advisability of applying the dielectric separator between the metallic layers of screen, let us calculate the screen attenuation of the screen of cylindrical construction with the different thickness of separator. Screen is steel-copper, frequency - 100 kHz, a radius of screen - 10 mm. Table 3.2 gives given data of the calculation of the screen attenuation of two-layered cylindrical screen with the different thicknesses of the dielectric separators between layers.

Application/use of the shims, close in thickness to

metallic layers (1 mm), does not give essential effect (difference altogether only 0.24 Np). The separator with a thickness of 10 mm is led to an increase in the screen attenuation on 0.75 Np. However, the application/use of this thick separator between metallic layers is clearly inexpedient, since it is connected with an increase in the overall sizes of screen and consumption of materials for its production.

Tables 3.2. Screen attenuation of two-layered screen (copper - steel) with the different thicknesses of the dielectric separator between layers.

(1) Толщина диэлектрической прокладки, мм	(2) Затухание медного слоя неп	(3) Затухание стального слоя неп	(4) Затухание взаимодействия неп	(5) Экранное затухание неп
0	3,4	2,2	—0,94	4,66
1	3,4	2,2	—0,70	4,90
4	3,4	2,2	—0,35	5,25
10	3,4	2,2	—0,19	5,41

Key: (1). Thickness of dielectric separator, mm. (2). Attenuation of copper layer Np. (3). Attenuation of steel layer Np. (4). Attenuation of interaction Np. (5). Screen

attenuation Np.

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3.7. Optimum constructions of the multilayer combined screens.

There is essential interest the determination of the most advantageous relationship/ratios of the thicknesses of the combined screens and in the establishment of initial positions from the development of the optimum screens of the combined construction. Bearing in mind that the greatest effectiveness in the multilayer combined screens gives combination of nonmagnetic (copper) and magnetic (steel) materials, let us examine first of all such screens.

Above in Section 3.5 it was shown, that the screen attenuation of two-layered screen is determined by the formula

$$A_{э12}=\ln\left|\frac{1}{S_{12}}\right|=\ln\left|\frac{S_1S_2}{1-P_1P_2}\right|=A_{э1}+A_{э2}+A_p$$

or

$$A_{э12} = \ln\left|\frac{1}{S_{12}}\right| = A_{п12} + A_{о12}.$$

For obtaining simpler and more demonstrative results, let us examine the conditions of engineering the optimum screens separately for the low-frequency ($\theta > t$) and high-frequency ($\theta < t$) zones of transmission. For a low-frequency range is characteristic the use of magnetic materials (steel) in magnetostatic mode/conditions. The screen attenuation of flat/plane steel screen is determined by formula $A_э^с = \ln 1+\mu t/4r_э$. The coefficient of reaction has a value, close k - 1, i.e., $P^с = -1$. The screen attenuation of copper screen in the range of low frequencies is determined by formula $A_э^м = \ln|1+\kappa^2 r_э t|$. The coefficient of reaction for this case is close to 0, i.e., $P^м = 0$.

The attenuation of the interaction of this two-layered screen (copper-steel) is equal to zero: $A_р = \ln(1 - P_1 P_2) = 0$.

The screen attenuation of two-layered screen will be

$$A_{э12} = \ln\left|\left(1+\kappa_1^2 r_э t_1\right)\left(1+\frac{\mu_2 t_2}{4r_э}\right)\right|.$$

Disregarding ones as compared with the second terms,

which stand in brackets, we will obtain $A_{э12}$ = ln $|k_1^2\mu_2 t_1 t_2/4|$ -, where indices 1 are related to copper layer, and indices 2 are to steel. Accurately the same expression is obtained for cylindrical and spherical screens. Therefore basic condition/positions and the conclusions of the present investigation for a low-frequency range are valid for all three structural/design varieties of screens (flat/plane, cylindrical, spherical).

For the determination of the most advantageous relationship/ratio of the thickness of the layer of the screen by which is reached the greatest value of screen attenuation, we investigate expression $A_{э12}$ to the maximum

$$\frac{\partial A_{э12}}{\partial t_1}=0 \text{ and } \frac{\partial^2 A_{э12}}{\partial t_1^2}<0. \quad (3.26)$$

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Taking into account that the general thickness t = t_1 + t_2, we will obtain $A_{э12}$ = ln $|Nt_1 (t-t_1)|$, where N = $k_1^2\mu_2/4$. Then

$$\frac{\partial A_{э12}}{\partial t_1}=\frac{t-2t_1}{tt_1-t_1^2}=\frac{t_2-t_1}{t_1 t_2}=\frac{1}{t_1}-\frac{1}{t_2}=0.$$

As a result we will obtain optimum condition in the form

$$t_1=t_2=t/2. \quad (3.27)$$

Thus, the most advantageous result is obtained with the equality of the thickness of the layer of copper and steel of two-layered steel-copper screen [2]. In this case, maximum screening effect is determined by the formula

$$A_{э12} = \ln\left|\frac{\kappa_1^2 \mu_2}{4} t_1^2\right|. \tag{3.28}$$

From formula it is evident that the screen attenuation is determined by the value of eddy currents in copper ($k_1 = \sqrt{i\omega\mu\sigma}$), by the value of magnetic permeability of steel (μ_2) and depends on the thickness of the layer of screen ($t_1 = t_C = t_M$). The obtained conclusions are valid for flat/plane, cylindrical and spherical screens in the range of frequencies to 10 kHz. Investigation and formulas (3.27) and 3/28) can be common for any combination of nonmagnetic (copper, aluminum, lead) and magnetic (steel, Permalloy) materials.

In a similar manner can be determined the optimum construction of a three-layered screen of the type "copper" [formula (3.15))]. In this case the most advantageous results are reached at the equality of the thicknesses of all layers of screen ($t_1 = t_2 = t_3 = t/3$), and screen

attenuation is determined by the formula

$$A_{9123} = \ln \left| \frac{\kappa_1^4 r_3 \mu_2}{4} t_1^3 \right| . \qquad (3.29)$$

The obtained result is propagated to the flat/plane, cylindrical and spherical screens of three-layered construction in the range of frequencies to 10 kHz. For a high-frequency range the most favorable effect is reached at the large thicknesses of magnetic metals (steel) and smaller - nonmagnetic metals (copper, aluminum).

A change of the optimum thickness of copper layer in percentages from the overall thickness of screen (t = 0.4 mm) is shown to Fig. 3.6. On curve/graph are clearly visible three frequency domains.

Range I is a direct current and very low frequencies (to 0.5 kHz). Here the best results gives purely uniform steel screen (t^M = 0o/o and t^C = 100o/o). This is caused by the facts that in the indicated frequency range the electromagnetic shadowing is virtually absent, and therefore screening effect of copper is negligible, but steel works in magnetostatic mode/conditions and gives very good results.

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Range II is the spectrum approximately from 0.5 to 10 kHz. For it can be recommended the equal thicknesses of copper and steel layers (t^M = 50o/o and t^C = 50o/o). The effective action of copper begins in electromagnetic mode/conditions, and steel continues to work predominantly in magnetostatic mode/conditions.

Range III is a frequency spectrum from 10-20 kHz to high frequencies. Both copper and steel operate in electromagnetic mode/conditions on the principle of eddy currents. From curve/graph it is evident that with an increase in the frequency the optimum thickness of copper layer decreases, and steel - it increases. So, if at frequency 7 kHz the optimum thickness of copper layer was 50o/o of the overall thickness of screen, then with f = of 110 khz it does not exceed 15o/o.

In the range of more high frequencies (approximately more than 1000 kHz) the compound/composite combined screen generally becomes meaningless, and from the viewpoint of shielding effect in preferred position is located by purely steel screen (t^M = 0o/o and t^C = 100o/o). This result has

completely logical physical explanation and it completely corresponds to the basic condition/positions of the wave theory of screens.

Above shown, that screening effect was caused by cumulative effect of the attenuation of reflection (A_o) and of the attenuation of absorption (A_n). There it is substantiated, that copper possesses high reflecting properties, and steel - by the high attenuation of absorption in metal. Therefore in the range of comparatively low frequencies (10-20 kHz), where prevails the factor of the attenuation of reflection, there is no need in thick steel screens. With an increase of frequency, grow/rises the specific role of the attenuation of absorption, screening effect of steel becomes more than copper, and therefore it is expedient to increase the thickness of steel layer.

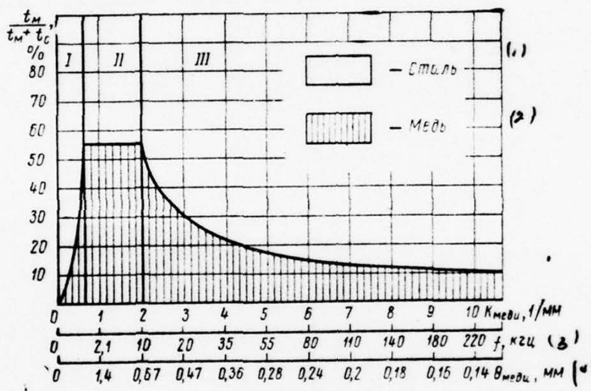

Fig. 3.6. Optimum relationship/ratio of the thickness of the layer of the combined screen (copper-steel).

Key: (1). Steel. (2). copper. (3). kHz. (4). copper, mm.

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In this case is realized the positive effect of the attenuation of the absorption of steel layer and is

preserved the proper value of the attenuation of reflection at a boundary dielectric-copper (A_0), which comparatively barely depends on thickness of the layer. Finally, in the range of even more high frequencies (about 1000 kHz), when the attenuation of absorption in steel ($A_п$) begins to predominate above the attenuation of reflection at a boundary dielectric - copper (A_0), it beccmes more effective the application/use of a purely steel screen.

To Fig. 3.7, are given the results cf the calculation of the screen attenuation of steel-copper screen with an cverall thickness of 0.4 mm with the different relationship/ratios of thicknesses they will stop and copper. Calculation is carried out at a radius of screen 17.5 mm and frequency 55 kHz. From the figure one can see that with an increase in the thickness of steel increases the parameter $A_п$ and it decreases A_0. The most advantageous effect gives the combined screen with thick steel layer (t^c=82o/o) and tonkim mednym sloem ($t^м$=18o/o). This screen gives to 1.3 Np more than uniform steel screen and on 2.4 Np more than the uniform copper screen of equivalent thickness.

The report/communications given above by choice of the

optimum relationship/ratios of the thickness of the layer of compound/composite screens and the construction of the two-layered combined screens remain valid for the three-layered and other constructions of screen.

To Fig. 3.8, are given the results of the calculation of a three-layered screen of the type "copper" with an overall thickness of 0.6 mm with the different thicknesses of copper and they will stop. Calculation is carried out for frequency 8 and 110 kHz. From curve/graph it is evident that at frequency 8 kHz the most advantageous effect gives the screen, which has equal on 0.2 mm thickness of the layers of copper and steel.

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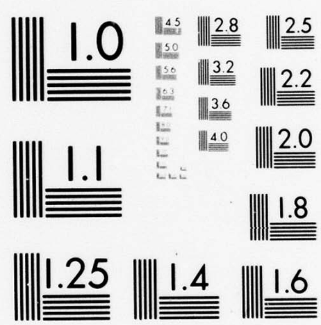

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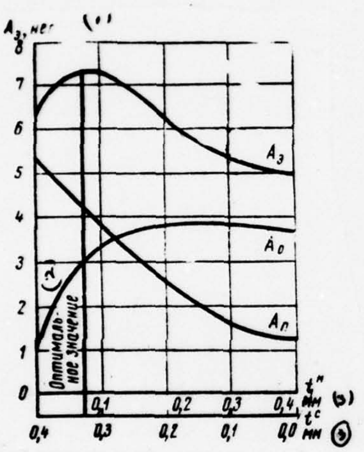

Fig. 3.7.

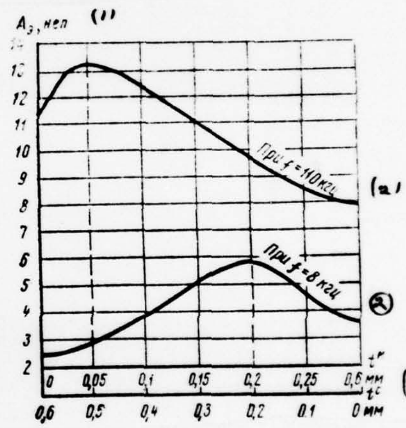

Fig. 3.8.

Fig. 3.7. Screen attenuation of two-layered screen with the different thicknesses of copper and steel.

Key: (1). blisses. (2). Optimum value. (3). mm.

Fig. 3.8. Screen attenuation of three-layered screen (copper-steel-copper) at the different thicknesses of copper and steel and different frequencies.

Key: (1). Np. (2). kHz. (3). mm.

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In the range of high frequencies sharply grow/rises the specific significance of steel. Here the best result gives screen. having copper layers on 0.05 mm, and steel layer, equal to 0.5 mm. In both cases the combined screen is more effective than the uniform copper or steel screen of equivalent thickness.

3.8. Multilayer screens in coaxial cables.

For an increase in the screening effect, the external wire-screen of coaxial cables is made composite. As a rule, it consists of the copper cylinder above which it is superimposed one-two layer of the winding of steel strip.

Are known also the three-layered constructions of the external wires of coaxial cable (copper-steel-copper).

Let us examine the shielding ability of the multilayer combined screens in coaxial cables. Electromagnetic waves can penetrate both through the internal and through the external surface of external wire. In the first case (Fig. 3.9a) cable itself is the source of interferences, in the second - the abcable is subjected to extraneous interferences (Fig. 3.9b).

In Table 3.3 gives the formulas of the engineering calculations f single-/monc-di- and three-layered screens in both mode/conditions of effect. Here $Z_M = \sqrt{i\omega\mu/\sigma}$ is wave independence of the metal $\kappa = \sqrt{i\omega\mu\sigma}$ - coefficient of eddy currents; t is thickness of screen.

Analyzing the given formulas, it can be noted that:

1. The coefficient of screening consists of two components: a) by that characterizing attenuation in thicker than screen and b) the caused by reflection energy on the boundaries of layers. Attenuation in thicker than the screen (attenuation of absorption) is expressed by chkt; the number of cosines corresponding to the number of layers of screen.

The attenuation of reflection is expressed as thkt and the relation of the wave impedance of the layers of screen; the number of these reflections corresponds to the number of boundaries of layers.

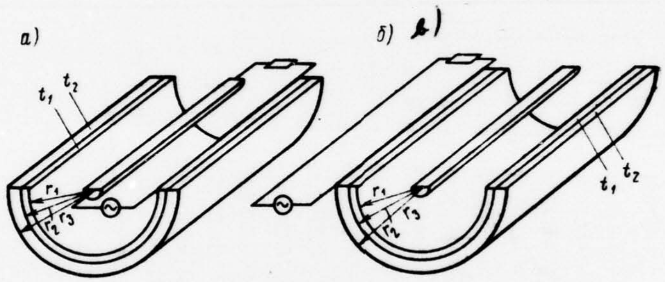

Fig. 3.9. On the calculation of the composite screens of coaxial cables: a) cable is the source of effect; b) cable is subjected to effect.

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So, at three-layered screen have two boundaries, and therefore formula contains two members, which characterize reflection (Z_{M1}/Z_{M2} and Z_{M2}/Z_{M3}). The more differs the wave impedance of boundary metals, that higher screening effect of multilayer screen.

2. Comparing these formulas with formulas for calculation of symmetrical shielded circuits, we see that in the case of coaxial cable there are no reflections on joints dielectric - metal - dielectric (S_0), characteristic to balanced cables. /

3. From the formula of three-layered screen (S_{123}) it is possible to obtain the formula of two-layered screen (S_{12}), if we accept t_3 = 0 and from formula S_{12} - the formula of single-layer screen (S_1), if we accept t_2 = 0.

Tables 3.3. Screening constants of the multilayer screens of coaxial cables.

TABLE 3.3.

(1) Конструкция экрана	(2) Расчетные формулы коэффициента
	(3) Коаксиальная пара является источником влияния
(4) Один слой	$S_1=\frac{1}{\mathrm{ch}\,\kappa_1 t_1}$
(5) Два слоя	$S_{12}=\frac{1}{\mathrm{ch}\,\kappa_1 t_1\,\mathrm{ch}\,\kappa_2 t_2}\cdot\frac{1}{\left(1+\frac{Z_{м1}}{Z_{м2}}\,\mathrm{th}\,\kappa_1 t_1\,\mathrm{th}\,\kappa_2 t_2\right)}$
(6) Три слоя	$S_{123}=\frac{1}{\mathrm{ch}\,\kappa_1 t_1\,\mathrm{ch}\,\kappa_2 t_2\,\mathrm{ch}\,\kappa_3 t_3}\times$ $\times\frac{1}{\left(1+\frac{Z_{м1}}{Z_{м2}}\,\mathrm{th}\,\kappa_1 t_1\,\mathrm{th}\,\kappa_2 t_2\right)\left(1+\frac{Z_{м2}}{Z_{м3}}\,\mathrm{th}\,\kappa_2 t_2\,\mathrm{th}\,\kappa_3 t_3\right)}$
	(7) Коаксиальная пара подвержена внешнему влиянию
(4) Один слой	$S_1=\frac{1}{\mathrm{ch}\,\kappa_1 t_1}$
(5) Два слоя	$S_{12}=\frac{1}{\mathrm{ch}\,\kappa_1 t_1\,\mathrm{ch}\,\kappa_2 t_2}\cdot\frac{1}{\left(1+\frac{Z_{м2}}{Z_{м1}}\,\mathrm{th}\,\kappa_1 t_1\,\mathrm{th}\,\kappa_2 t_2\right)}$
(6) Три слоя	$S_{123}=\frac{1}{\mathrm{ch}\,\kappa_1 t_1\,\mathrm{ch}\,\kappa_2 t_2\,\mathrm{ch}\,\kappa_3 t_3}\times$ $\times\frac{1}{\left(1+\frac{Z_{м2}}{Z_{м1}}\,\mathrm{th}\,\kappa_1 t_1\,\mathrm{th}\,\kappa_2 t_2\right)\left(1+\frac{Z_{м3}}{Z_{м2}}\,\mathrm{th}\,\kappa_2 t_2\,\mathrm{th}\,\kappa_3 t_3\right)}$

Key: (1). Construction of screen. (2). Calculation formulas of coefficient. (3). Coaxial line is the source of effect. (4). One Layer. (5). Two Layers. (6). Three Layers. (7). Coaxial line is subjected to external effect.

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4. Screening constant S is complex quantity. Its module/modulus characterizes the degree of shadowing, and angle shows phase displacement between electromagnetic fields outside, also, within screen.

5. Shielding properties of coaxial line, which operates as affecting circuit (for example, S_{12}), are less than pair, subjected to effect (S_{21}).

Between screening constants, there is the approximately following relationship/ratio:

$$S_{21} \approx S_{12} \frac{Z_{M2}}{Z_{M1}}, \qquad (3.30)$$

while between the screen attenuations

$$A_{э21} \approx A_{э12} + \ln \left| \frac{Z_{M2}}{Z_{M1}} \right|. \qquad (3.31)$$

Since for a composite screen (copper-steel) Z_{M2}/Z_{M1} = $Z^{C}/Z^{M} \approx 28$, respectively the difference in the screen attenuation of the cable, subjected to effect, is more than the affecting cable approximately on ln 28 = 3.3 Np.

6. Screening effect grow/rises with an increase of frequency and thicknesses of screen. The greater the layers, that more screening effect. The multilayer screen, equivalent according to thickness to single-layer screen, has the best characteristics because of the effect of reflection at a boundary of the coupling of different metals.

Let us examine in more detail the optimum constructions of two-layered and three-layered screens.

Two-layered screens. Let us establish/install the shielding characteristics of coaxial line with the different thicknesses of copper and steel layers and let us determine the most advantageous relationship/ratio of layers a composite screen.

Tables 3.4. Screening effect $A_{э}$ and the resistor/resistance of losses $R_{э}$ in composite screen with the different relationship/ratios of copper and steel.

TABLE 3.4.

$t_м$, мм (1)	t_c, мм (1)	$\frac{t_м}{t_c}$, %	$A_{эпз}$, нен (2)	$R_э$, $\frac{ом}{км}$ (3)
0	0,8	0	11,60	102,0
0,05	0,75	6,25	13,15	—
0,1	0,7	12,5	10,55	6,08
0,2	0,6	25,0	8,70	3,17
0,3	0,5	37,5	7,44	3,09
0,4	0,4	50,0	6,58	3,09
0,5	0,3	62,5	5,34	3,09
0,6	0,2	75,0	4,07	3,09
0,7	0,1	87,4	2,71	3,09
0,8	0	100	2,25	3,09

Key: (1). mm. (2). Np. (3) ohms/km.

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Table 3.4 gives corrected values of the attenuation of shadowing $A_э$ and of the resistor/resistance of losses $R_э$ in the composite screen of coaxial line with the different relationship/ratios of the thicknesses of copper and steel,

but with the constant overall thickness of screen $t = t_M + t_C = 0.8$ mm and to frequency 60 kHz. From table it is evident that between the copper and steel layers of screen is a optimum relationship/ratio. The attenuation of shadowing reaches the maximum value at $t_M = 0.05$ mm and $t_C = 0.075$ mm. In this case $A_{\ni 12}$ of composite screen, is 13.15 Np, while the steel screen of the same thickness gives $A_{\ni} = 11.6$ Np, and copper - $A_{\ni} = 2.25$ Np.

The relationship/ratio of the thicknesses of copper and steel layers affects also the losses, introduced by screen into the circuit of transmission. With an increase in the copper layer, value $R_{\ni}$ falls, and then is stabilized on the determined value. With optimum, in the relation to screen attenuation, the relationship/ratio of the layers ($t_M = 0.05$ and $t_C = 0.75$) of energy loss are sufficiently considerable, which makes this construction virtually unacceptable. Furthermore, in production sense it is extremely difficult to use copper layer by the thickness altogether only 0.05 mm. In the existing constructions of coaxial lines, copper and steel layers are located approximately in relationship/ratio 3:5.

In connection with the screen in question with an

overall thickness of 0.8 mm value $t_м$ 0.3 mm and $t_с$ = 0.5 mm. As can be seen from Table 3.4, with this relationship/ratio is obtained sufficient screening effect (7.44 Np) with the low losses of energy. Value $R_э$ of composite screen is equal to $R_э$ copper screen and it is 3.09 Ω/km. From Fig. 3.10, where is represented dependence $A_э$ of copper, steel and composite screens from the overall thickness of screen t it is apparent that screening effect on the order of 7 Np at frequency 60 kHz can be provided with the thickness of the screen: copper 2.1 mm, steel 0.5 mm and bimetallic 0.8 mm ($t_м$ = 0.3; $t_с$ = 0.5).

Three-layered screens. The results of the calculation of the attenuation of shadowing $A_{э123}$ of a three-layered screen of the type "aluminum" with an overall thickness of 0.2 mm are given in Table 3.5. Here is shown the specific significance of screen attenuation because of absorption in aluminum ($A_п^а$), in steel ($A_п^с$) and because of reflection at a boundary aluminum-steel ($A_o^{а-с}$) and steel-aluminum ($A_o^{с-а}$).

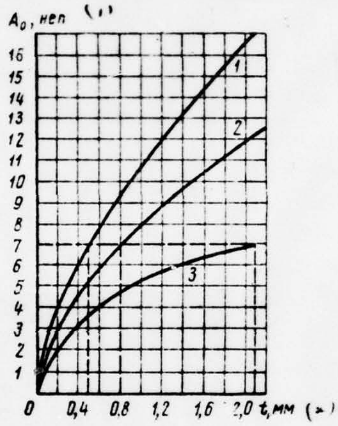

Fig. 3.10. Screen attenuation depending on the thickness of screen made of steel (1), bimetal (2) and copper (3).

Key: (1). Np. (2). mm.

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To Fig. 3.11, is given the frequency dependence of

screen attenuation ($A_{э123}$) of three-layered screen (aluminum-steel-aluminum) with different thickness of the layer (general thickness of screen 0.2 mm), while to Fig. 3.12, are shown the values of the components of the screen attenuation $A_{п}^{э}$, $A_{п}^{c}$, $A_{о}$ for this same three-layered screen at frequency 100 kHz.

Tables 3.5. Screening effect of three-layered screens.

(1) Толщина слоев экрана, мм	f, гц	$A_{п}^{c}$	$A_{п}^{a}$	$A_{о}^{а-с}$	$A_{о}^{с-а}$	$A_{э}$
0,1—0,18—0,01	30	3,03	0,001	0,000	0,67	3,70
	60	3,52	0,002	0,002	0,70	4,23
	100	4,03	0,003	0,003	0,80	4,82
	310	5,56	0,008	0,005	0,96	6,53
	550	6,08	0,010	0,008	1,01	7,11
0,05—0,10—0,05	30	1,39	0,02	0,004	1,73	3,14
	60	1,66	0,04	0,008	1,78	3,49
	100	1,93	0,07	0,010	1,93	3,94
	310	2,77	0,20	0,020	2,05	5,04
	550	3,08	0,35	0,040	2,18	5,65
0,09—0,02—0,09	30	0,08	0,06	0,003	1,46	1,61
	60	0,11	0,13	0,004	1,50	1,81
	100	0,13	0,21	0,009	1/78	2,13
	310	0,23	0,61	0,020	2,11	2,96
	550	0,26	1,01	0,030	2,12	3,42

Key: (1) the thickness of the layer of screen, mm.

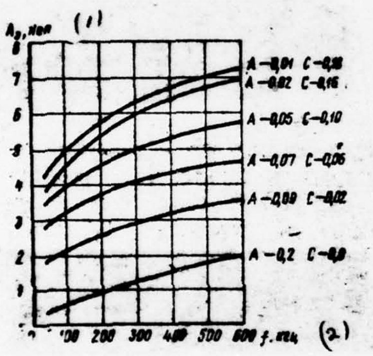

Fig. 3.11

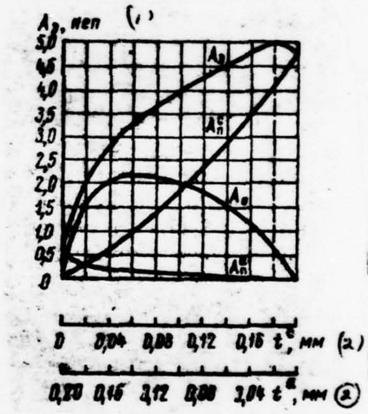

Fig. 3.12.

Fig. 3.11. Frequency dependence of screened attenuation of the three-layered screen of construction luminum-steel-aluminum with different thickness of the layer total thickness of screen 0.2 mm).

Key: (1). Np. (2). kHz.

Fig. 3.12. Components of screened absorption (A_{Π}^{∂} and A_{Π}^{c}) and of reflections (A_0) in the three-layered screen of construction aluminum-steel-aluminum at frequency 100 kHz and the different thicknesses of screen.

Key: (1). Np. (2). mm.

Page 87. From given data it follows that the combined three-layered screen of the type "aluminum" in all cases is better than the uniform aluminum screen; greatest screening effect is reached at the thin layers of aluminum and the thick layers of steel. Optimum is the construction of screen of aluminum-steel-aluminum with respect 0.01-0.18-0.01 mm, respectively, in thickness of the layer.

The values of screen effect from absorption ($A_{\Pi} = A_{\Pi}^{c} + A_{\Pi}^{\partial}$) and reflection ($A_0 = A_0^{\partial - c} + A_0^{c - \partial}$) for are different frequencies and the thickness of the layer of the combined screen are different. In screens with thick steel layer, is more the effect of absorption, while in screens with the thickened aluminum layer, prevails the effect of reflection.

Moreover reflection at a boundary of layers steel - aluminum is substantially more than reflection at a boundary aluminum-steel. from Fig. 3.12 is evident that with an increase in the thickness of steel sharply grow/rises the absorption in steel and it decreases absorption in aluminum, and the effect of reflection has a maximum with the relationship/ratio of layers 0.07-0.06-0.07 mm.

end section.

Chapter 4.

Shielding of communication cables.

4.1. Types of cable shields.

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The stability of communication/connection and its quality during transmission with respect to cable lines to large distances to a considerable degree are defined by the protection of coupling circuits both from mutual and outside interferences. Most radical safety method of coaxial and symmetrical cable circuits from interferences is their shielding.

Cable shields have cylindrical form and most frequently

they are fulfilled in the form of continuous shells either in the form of the spirally superimposed winding from flat/plane tapes or in the form of cover/braid from fine/thin wires. Shields they manufacture, mainly, from lead, copper, they stopped or aluminum, and furthermore, there can be the composite and multilayer combined shields where the indicated materials are alternated in the most advantageous combination.

In cables with external plastic shells for protection from outside interferences, there are applied tape/strip type shields predominantly from the aluminum, copper, steel strips, superimposed spirally or longitudinally along cable.

By construction and according to operating principle, the shields are divided into those who shield from outside interferences and from internal (mutual) interferences. The sources of outside interferences are high-voltage electric power lines, contact circuits of electric railroads, man-made interferences, atmospheric electricity and powerful radio stations. The role of shields fulfill the metal shells, arrange/located above cable core. As a rule, they have continuous construction and are fulfilled made of lead, aluminum or steel (Fig. 4.1). Known also two-layered constructions of shells of the type aluminum-lead, aluminum - steel, etc.

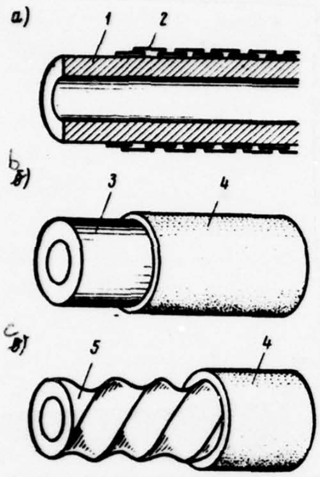

Fig. 4.1. External metal cable sheathings of the communication/connection: a) lead (MKSB); b) aluminum (MKSAP); c) steel (MKSSP); 1 - lead; 2 - steel strip; 3 - aluminum; 4 - polyethylene; 5 - steel.

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The screens, which shield from internal (mutual) interferences, are the component element of the most cable core. In this case into screen, consist the circuits with high transmission level and is provided the possibility of the organization of high-frequency communication/connection along single-cable system (it runs itself one cable). In

single-cable communication/connection the screens electrically divide the circuits of direct/straight and opposite directions and eliminate interferences between them.

In coaxial cables for providing the required norms of interference shielding in single-cable communication/connection, external wire is fulfilled composite. As a rule, it consists of the copper cylinder, above which is superimposed the winding from one-two layers of steel strip. Are known also trimetal screens of construction copper - steel - copper.

In the balanced cables of single-cable system, are applied multilayer separating screens. To Fig. 4.2, is shown the symmetrical shielded cable of single-cable communication/connection for a system K-60. Screen has three-layered tape/strip construction (copper - steel - copper) 0.1 mm in thickness of the layer.

In the radio-frequency cables of antenna feeder designation/purpose, are applied the screens of flexible construction of the type of cover/braid made of copper or steel wires.

In low-frequency cables are shielded separate wires and circuits with high transmission level (circuit of broadcasting, wirephoto, signal wires, etc.). As screens here is applied metallized paper or aluminum foil.

4.2. Continuous screens.

In cable technology are applied the protective shells, mainly, from lead or aluminum. Recently appeared also the steel fluted shells. The shielding characteristics of cables are improved during the use of two-layered shells of construction aluminum - lead and aluminum - steel. Aluminum is superimposed in the form of spiral strip or shells.

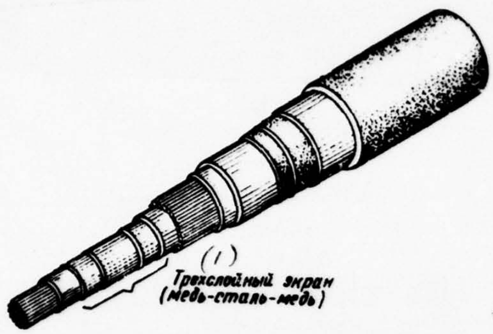

Fig. 4.2. Shielded cable of single-cable communication/connection.

Key: (1). three-layer shield (copper - steel - copper).

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The shielding characteristics of cables also affect the armor deposits from steel strips, available at the cables, intended for a separator directly into the earth/ground.

The screening constant symmetrical communication cables with a capacitance/capacity of 4 x 4 with shielding shells of lead, aluminum they became given in Table 4.1, but coaxial cables - in Table 4.2. Dampings of the

shielding of the cable sheaths of relatively magnetic field over a wide range of frequencies are given in Table 4.3.

The values of the screening constant of the different types of cables (urban, coaxial, symmetrical) are given to Figs. 4.3 and 4.4.

Table 4.1. Screening constant of balanced cables with capacity 4 x 4 with different protective shells.

f гц (1)	Eоб в/км (2)	МКСБ	МКСАП	МКСАПБ	МКСАСПБП	МКССП	МКОСП
50	10	0,76		0,22	0,27	0,95	0,79
	20	0,74		0,20	0,24	0,95	0,68
	30	0,67		0,18	0,21	0,80	0,6
	50	0,55	0,56	0,15	0,16	0,80	0,47
	100	0,40		0,11	0,11	0,85	0,34
	200	0,35		0,10	0,09	0,90	0,42
	300	0,41		0,14	0,14	0,95	0,54
150	5	0,45	0,20	—	—	—	0,50
	10	0,53		—	0,1	—	0,47
300	5	0,25	0,12	—	—	—	0,3
	10	0,25		0,48	0,05	0,72	0,30
800	5	0,091	0,05	—	—	—	—
	10	0,090		0,15	0,019	0,45	0,14
	70	0,090		0,14	0,018	0,38	0,097
3000	5	0,026		0,048	0,0048	0,12	0,033
	10	0,025	0,014	0,048	0,0048	0,12	0,033
	70	0,028		0,048	0,0048	0,12	0,026
5000	5	0,021		0,003	0,0033	—	0, 016
	10	0,021	0,01	0,003	0,0033	0,08	0, 015
	70	0,019		0,003	0,0033	0,066	0, 013
(3) Сопрот. постоян. току, ом/км		2,12	0,53	0,42	0,4	6,25	2,6
(4) Конструкция оболочки		(5) свинец 1,25 мм, стальные ленты 0,5мм	(6) алюминий 1мм	(7) алюминий 1мм, стальные ленты 0,5мм	(8) алюминий 1мм, свинец 1,25 мм, стальные ленты 0,5 мм	(9) сталь 0,4мм	(10) алюминиевые ленты 0,2мм сталь 0,4мм

Key: (1). Hz. (2). V/km. (3). Resist. direct current Ω/km. (4). Construction of shell. (5). lead 1.25 mm, steel strips 0.5 mm. (6). aluminum 1 mm. (7). aluminum 1 mm, steel strips 0.5 mm. (8). aluminum 1 mm, lead 1.25 mm, steel strips 0.5 mm. (9). steel 0.4 mm. (10). aluminum strips 0.2 mm steel 0.4 mm.

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Table 4.2. Screening constant of the cable sheaths of coaxial cables.

f, гц (1)	E, в/км (2)	КМБ-4	КМАБ-4	КМБ-8/6	КМБ-6/4
50	10	0,60	0,10	0,46	0,60
	20	0,58	0,093	0,38	0,54
	50	0,52	0,064	0,30	0,46
	100	0,46	0,043	0,21	0,37
	150	0,36	0,040	0,17	0,27
	200	0,34	0,041	0,15	0,25
	250	0,33	0,044	0,14	0,30
	300	0,34	0,055	0,15	0,32
300	50	0,24	0,018	0,085	0,15
	100	0,20	0,015	0,080	0,14
800	50	0,067	0,008	0,028	0,049
	100	0,064	0,007	0,026	0,048
1500	50	0,036	0,0042	0,016	0,027
	100	0,035	0,0041	0,016	0,026
2000	50	0,025	0,0028	0,012	0,020
	100	0,025	0,0026	0,012	0,020
3000	50	0,018	0,0022	0,010	0,015
	100	0,018	0,0022	0,010	0,015
5000	50	0,015	0,0012	0,006	0,011
	100	0,015	0,0012	0,006	0,011

Key: (1). Hz. (2). V/km.

Table 4.3. Attenuation of shielding of different cable sheaths over a wide range of frequencies.

(1) f, кгц	МКСБ 4x4	МКСБ 7x4	МКСАП 4x4	МКСАПБ 4x4	МКСАСПБП 4x4	МКСАПБ 7x4	МКССП 4x4	МКССП 4x7
10	3,7	4,3	5,27	5,55	6,33	5,8	3,52	5,37
20	4,1	4,75	6,01	6,25	7,34	6,6	4,75	6,89
50	5,0	5,75	7,25	7,4	9,63	7,7	7,12	8,75
100	5,85	6,7	8,26	8,35	11,4	8,7	9,74	10,9
150	6,45	7,3	8,74	8,8	—	8,9	11,2	11,4
200	6,9	7,8	—	9,05	14,0	9,55	—	—
250	7,25	8,15	—	9,25	—	9,75	—	—
300	7,45	8,35	—	9,4	—	9,9	—	—
(2) Конструкция оболочек	(3) свинец 1,25мм стальные ленты 0,5мм	свинец 1,3мм стальные ленты 0,5мм (3)	(4) алюминий 1мм	алюминий 1мм стальные ленты 0,5мм (5)	(6) алюминий 1мм свинец 1,3мм стальные ленты 0,5мм	алюминий 1мм стальные ленты 0,5мм (5)	(7) сталь 0,4мм	(8) алюминиевые ленты 0,2мм сталь 0,4мм

Key: (1). kHz. (2). Construction of shells. (3). lead —— mm steel strips —— . (4). aluminum 1 mm. (5). aluminum 1 mm steel strips 0.5 mm. (6). aluminum 1 mm lead 1.3 mm steel strips 0.5 mm. (7). steel 0.4 mm. (8). aluminum strips 0.2 mm steel 0.4 mm.

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From given data it follows:

1. Aluminum shell has substantially better shielding characteristics, than lead and steel. In a comparatively low frequency band (to 5 kHz) the shielding characteristics of

cable in steel shell (MKSSP 4 x 4) and the lead armored cable (MKSB 4 x 4) are approximately analogous, while in the range of high frequencies, the cables in steel shell possess substantially the best characteristics. Best screening effect is reached during the application/use of a two-layered shell of the type" aluminum" - steel. Aluminum possesses good conductivity, steel - by high magnetic properties.

2. Shielding properties of shells, containing magnetic material (steel), depend substantially on value of longitudinal emf (E°_{o6}), induced in shell. As can be seen from Fig. 4.3, with an increase emf, the value of screening constant decreases at first, and then, after achieving the minimum, somewhat grow/rises. This is caused by the dependence of magnetic permeability on the value of magnetic intensity in steel. The shielding properties of nonmagnetic materials do not depend on value emf in shell.

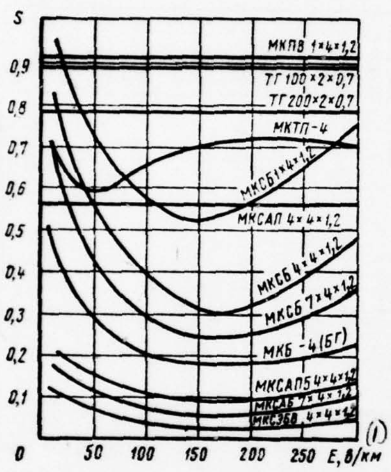

Fig. 4.3.

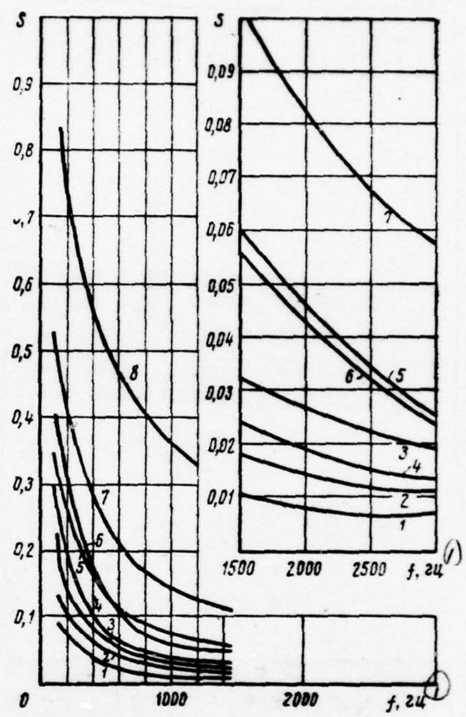

Fig. 4.4.

Fig. 4.3. Screening constant of different cables with f = 50 Hz.

Key: (1). V/km.

Fig. 4.4. Frequency dependence of the screening constant of different cables with the longitudinal emf of 60-70 V/km: 1 - MKSBP 4 x 4; 2 - KMB-4; 3 - MKSB 7 x 4; 4 - MKSAP

4 x 4; 5 - MKTP-4; 6 - MKSB 4 x 4; 7 - MKSB 1 x 4; 8 - MKP 1 x 4.

Key: (1). Hz.

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3. Increase in diameter of cable, and also thickness of shell gives noticeable improvement in shielding properties.

Were above corrected values of screening constants under the idealized conditions. Under actual conditions the shielding properties of cables depend on the conditions of grounding, length of cable, and also the state of circuit "shell-ground". In all cases real screening effect is worse than ideal.

Fig. 4.5 shows the dependence of the real value of the coefficient of shielding on value $\gamma_{об}l$, where $\gamma_{об}$ — the propagation factor of circuit "shell-ground" and l — the length of cable. At low values $\gamma_{об}l$, that corresponds to the case of the ruby-colored length of cable or low

value of propagation factor (insulation of shell from ground), F is small and screening effect sharply descends. At large values $\gamma_{o6}l$, i.e., with the large length of cable or the large propagation factor, F $\longrightarrow$ 1 and real screening effect reaches ideal.

Cables with jute deposit in comparison with cables in plastic shell have better relationship/ratic between the real and ideal shielding coefficient. This is caused by large value γ_{o6} of jute cables.

They substantially affect the value of the real screening constant of the value of earth resistance. The lesser the value of earth resistance, the real screening effect. Tc Fig. 4.6, is shown the value of the real screening constant with different values of earth resistance and lengths of cable (cable MKSB, 4 x 4 with f = 50 Hz),. Here shown ideal value of screening constant.

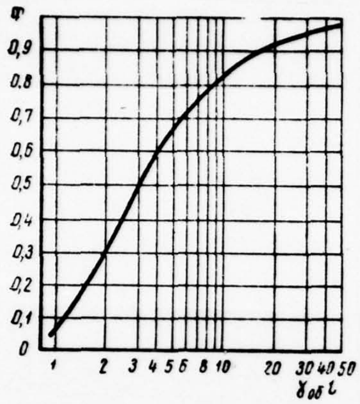

Fig. 4.5.

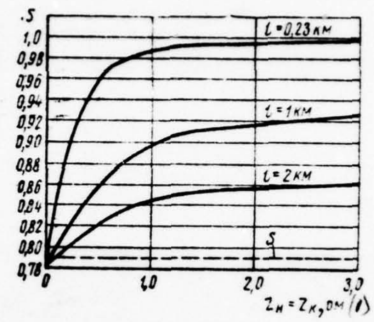

Fig. 4.6.

Fig. 4.5. Coefficient, which characterizes real screening effect.

Fig. 4.6. Real screening constant with the different values of earth resistance and at lengths of cable.

Key: (1). ohm.

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For providing a good value of real screening constant, it is necessary to have low earth resistance, and in cables

with plastic deposit periodically along route to equip groundings (through every 2-3 km).

The analysis given above proceeds from the condition that near cable there are no other extended metallic object/subjects. If at trench lie/rests not one, but several cables or are surrounding metallic masses, then screening effect noticeably is improved. Moreover the thicker the cables, the greater the screening effect. This is graphically illustrated by curve/graph Fig. 4.7, where is shown the dependence of screening effect on the number of cables and their diameter. For example, for the cables with a diameter of 40 mm the presence of two adjacent cables is led to an improvement in screening effect two times.

4.3. Tape/strip screens.

Tape/strip type screens are fulfilled from copper, aluminum or steel strips. Strips are superimposed on the shielded groups, splice or cable as a whole in the form of fish winding or it is longitudinal along cable. Screen strips can be superimposed butt (Fig. 4.8), and also with positive and negative overlap (with the gap between strips). Tape/strip screens can be both single-layer and multilayer.

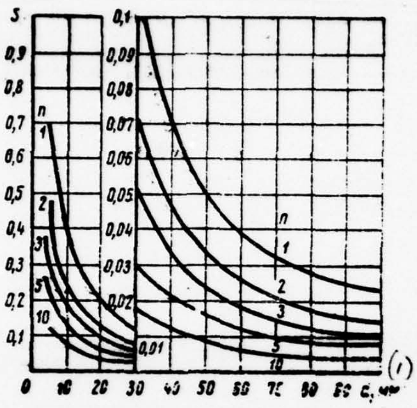

Fig. 4.7. Screening effect of urban telephone cables of the type TG at frequency 800 Hz depending on diameter under lead covering with the different number of cables in channeling.

Key: (1). s, mm.

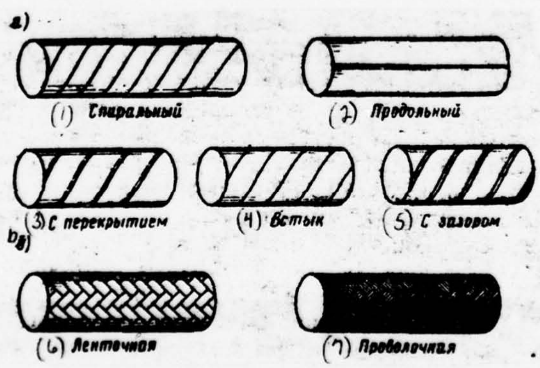

Fig. 4.8. Tape/strip (a) and braided (b) shields.

Key: (1). Spiral. (2). Longitudinal. (3). With overlap. (4). Butt. (5). With gap. (6). Tape/strip. (7). Wire.

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Are known the combined tape/strip shields of the type copper-steel-copper, aluminum-steel, etc.

Tape/strip type screens widely are applied in cable technology. They are the component element of communication cables in plastic shells, which shields circuits from outside interferences and which stabilizes the parameters of the transmission of cables. Tape/strip type multilayer combined screens perform also the role of the separating screens, which separate/liberate the circuits of direct/straight and opposite directions in single-cable communicating system.

The shielded groups, lays have, as a rule, winding structure. Therefore it is logical to expect that between pitch of strands of screen and cable is a determined optimum relationship/ratio. Furthermore, there are optimum dependences between the thickness of the layer of multilayer

tape/strip screens and the superposition methods of layers.

Below are set forth the results of the investigation of tape/strip type multilayer combined screens and are given the fundamental principles of the construction of such screens. Tape/strip screens, on the basis of the technological special feature/peculiarities of cable works, have predominantly spiral form. The width of screen strip (c) is connected with the angle of imposition (α), by winding pitch ($h_э$), by the diameter of the shielded part of the cable ($d_э$) by relationship/ratio $c=h_э\cos\alpha=\pi d_э\sin\alpha$. This follows directly from Fig. 4.9, where is depicted the scanning/sweep of one splice of screen strip to plane. The greater the diameter of cable ($d_э$), facts wider must be strip. Between the width of screen strip and winding pitch, also there is a direct dependence. In limiting cases when α = 90° width of strip $c=\pi d_э$, and when $\alpha \longrightarrow 0$ value c $\longrightarrow 0$. In real cable make-ups the overlap angle (α) is found from 30 to 80°.

Let us examine the dependence of screen attenuation on the space of the imposition of screen strips ($h_э$) and let us determine the effect of the mismatch of the space of screen strips ($h_э$) and pitch of strand of circuit ($h_п$).

To Fig. 4.10, are shown the results of the measurements of spiral screens with the different relationship/ratios of the space of the imposition of screen $h_э$ and of pitch of strand of circuit $h_п$ and during the different constructions of screens. Pitch of strand of circuit $h_п=100$ mm. Frequency of the measurements 110 kHz. For the development/detection of the effect of contact resistance between screen strips on screening effect measurement underwent also the screens, made from strips with the lacquered surfaces. The maximum value of shield attenuation occurs when $h_э=h_п$.

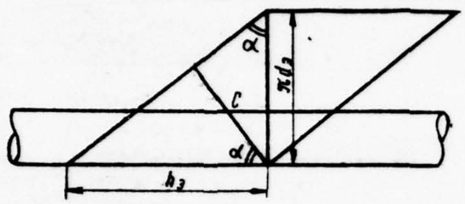

Fig. 4.9. Sweep circuit of one splice of screen strip.

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In this case all the structural/design varieties of screens (overlap, joint, gap) give the best effect. In the absolute value of value $A_э$ for the different constructions of screens when $h_э=h_п$ comparatively they differ little from each other. At the mismatched spaces $(h_э \neq h_п)$ and the presence of gaps, value $A_э$ sharply changes. So, if when $h_э=h_п$ the screen attenuation of the strips, superimposed with gap 3 mm, is 2.6 Np, then when $h_э/h_п=0{,}5$ value $A_э$ decreases to 1.6 Np. An increase in the gap is led to a regular decrease in screening effect.

With matched pitch of strands of circuit $h_п$ and of the winding of screen strips $h_э$ the presence of gaps and

slots in screen manifests itself comparatively little. So the gaps with a width of 10 mm when $h_э/h_п=1$ decrease value $A_э$ altogether only by 0.4 Np, while when $h_э/h_п=0,5$ decrease is 2 Np.

To Fig. 4.11, is given the frequency dependence of the screen attenuation of spiral screens with the different width of shield strip [c = 7/7 mm (a) and 30 mm (b)]. Pitch of strand of circuit 100 mm. Here corrected values $A_э$ of continuous cylindrical screen. The shielding characteristics of screen substantially affects the width of screen strip. With narrow strip screen attenuation is lower than with wide.

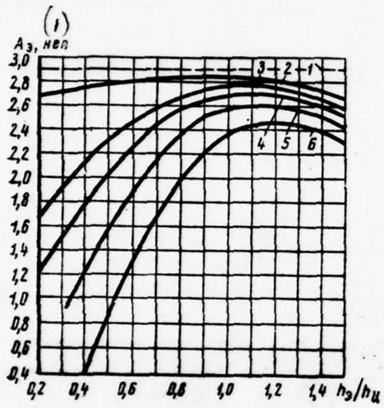

Fig. 4.10.

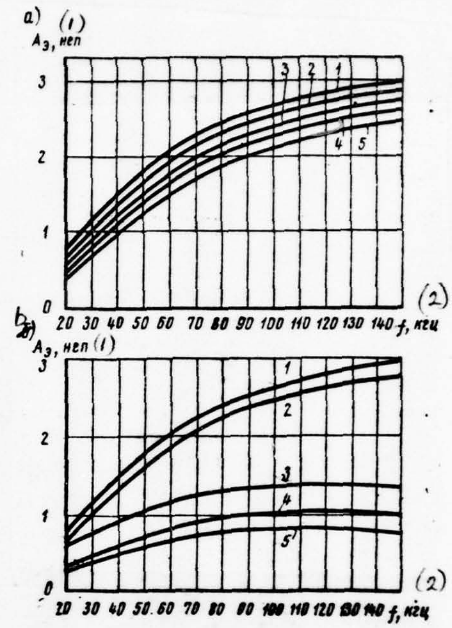

Fig. 4.11.

Fig. 4.10. Results of the measurement of spiral screens with different relationship/ratios $h_э/h_ц$ ($h_ц$=100 мм). where 1 - cylindrical screen (1 = 0.08 mm); 2 - copper strip with overlap; 3 - copper strip with overlap (lacquered); 4 - copper strip butt; 5 - copper strip (gap 3 m); 6 - copper strip (gap - 10 mm).

Key: (1). Np.

Fig. 4.11. Results of the measurement of screening effect

with the different width of copper screen strips (c) C = 30 mm (a) and C = 71 mm (b), where 1 - cylindrical screen; 2 - strip with covering; 3 - strip butt; 4 - strip with gap 3 mm; 5 - strip with gap 10 mm.

Key: (1). Np. (2). kHz.

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Especially substantially the width of strip affects during its imposition butt, also, with gaps. So, with narrow strip gap 3 mm by frequency 150 kHz descends $A_э$ almost by 2 Np, and with wide strip - altogether only by 0.35 Np. The frequency dependence of screen from narrow strips with gaps has flatter character, than in the screen, made from wide strips. With an increase in matched pitch of strand $(h_э=h_п)$ grow/rises screening effect and the best results they are reached when $h_э=h_п \rightarrow \infty$.

The frequency dependence of the screen attenuation of multilayer screens with the different methods of the imposition of screen strips is given to Fig. 4.12. In all cases copper layers were superimposed equally with overlap,

and steel strip was superimposed: with gap (1), butt (2) and with overlap (4). Furthermore, was checked the effectiveness of the imposition of two steel strips with gap (3), the second strip overlapping the gaps of the first strip. Here for a comparison are given the results of the measurement of five-layer steel-copper screens (5). In all cases were utilized the copper strips with a width of 30 mm and with a thickness of 0.08 mm, steel strips - by the width of 25 mm and by the thickness of 0.1 mm. Overlap of strips gives essentially the best results (on 1 Np), than the imposition of strips butt, also, with gap. The difference between the imposition of strips butt and with gap is altogether only 0.2-0.3 Np. The third superposition method of strips (two strips with gap) is virtually eqivalent to the imposition of strips with overlap.

Keeping in mind the technological difficulties of the imposition of steel strip with overlap, it is expedient if necessary of obtaining the large values A, to apply the superposition method of two steel strips with gap. Five-layer screen in comparison with the best constructions of three-layered screens gives supplementary effect in 1, -1.5 Np.

Comparing the effect of gaps in the screens of multilayer and single-layer constructions, it can be noted that in multilayer constructions it manifests itself considerably less

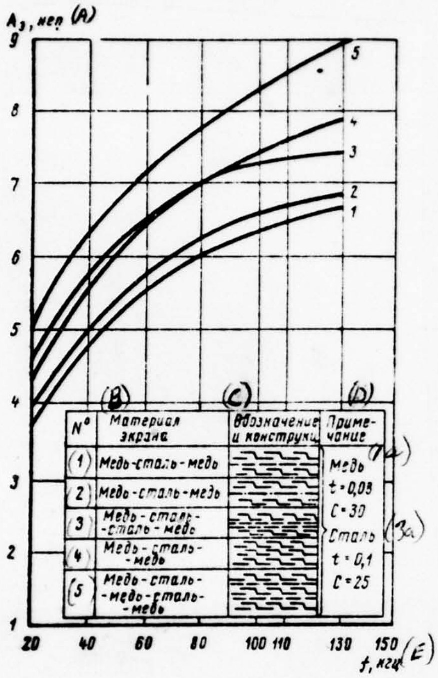

Fig. 4.12. Results of the measurement of the shielding properties of multilayer screens from strips.

Key: (A). Np. (B). Material of screen. (C). Designation and construction. (D). Note. (1). Copper - steel - copper. (1A). Copper. (2). Copper - steel - copper. (3). Copper - steel - steel - copper. (3a). Steel. (4). Copper - steel - copper. (5). Copper - steel - copper - steel - copper. (E). kHz.

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This is explained to the facts that in the multilayer screen constructions of the slot of one layer they overlap with the strip of another layer, and therefore the emission/radiation of energy decreases.

On Fig. 4.13, is given comparative evaluation of different constructions of screens according to their screening effect in wide frequency spectrum. The best result provide continuous shells and two-layered shells. The two-layered shell, which consists of copper strip and steel cover/braid, gives in comparison with other types of the measured screens the greatest screening effect, moreover it is effective both in the tone frequency spectrum and in the range of high frequencies.

A screen of the type of steel cover/braid gives a good effect in the range of low frequencies, and in the range of high frequencies, its action substantially descends on the strength of emission/radiation from slots. The screening effect of copper cover/braids depends on the density of the imposition of wires. At frequency 1 MHz, the cover/braid of 100o/o density possesses on 1.5 Np

greater screen attenuation than the cover/braid of 50o/o density.

The action of the metallized paper as electromagnetic screen is developed only with 20 kHz; in terms of absolute value its effect is very small.

To Fig. 4.14, are given the results of the measurement of the screening effect of the semi-conducting electrical shell with the grounding through different intervals along the length of cable. From curve/graphs it follows that the grounding of screen gives essential effect in a decrease in the effect of electrostatic field. Grounding at both end/leads of the cable gives screen attenuation on 1 Np more than at one end/lead. The more frequent along the length of cable is arranged the grounding, the. With an increase of frequency, the effect of grounding decreases.

During the determination of the optimum construction of cable separating screen, it is necessary along with the shielding characteristics to consider also the reaction of screen and v, the first turn, the electrical losses, introduced by screen into the circuit of transmission.

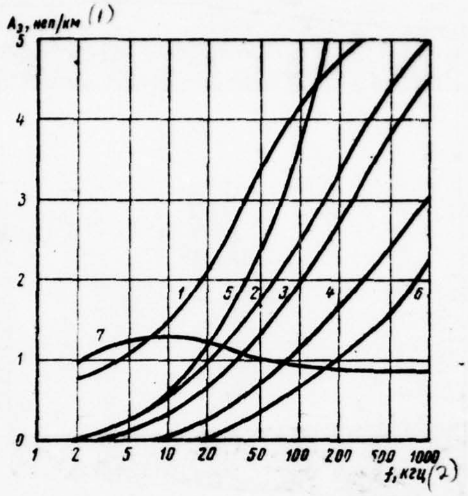

Fig. 4.13. Results of measurement of the screens of the different construction: 1 - copper strip and steel cover/braid; 2 - copper strip; 3 - copper cover/braid (100o/o density); 4 - copper cover/braid (50o/o density); 5 - lead covering; 6 - metallized paper; 7 - rare steel cover/braid (d of wires 0.24 mm).

Key: (1). Np/km. (2). kHz.

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To Fig. 4.15, are given the results of the measurements of the different constructions of two-layered

screens in the spectrum to 150 kHz. In all cases copper was arrange/located nearer to the source of interferences. Thickness of copper strip 0.08 mm, wirina - 27 mm; the thickness of steel strip 0.1 mm, width - 25 mm. From the character of frequency dependence and absolute values findings can be divided into two groups.

In the first group enter the screens with electrically uniform are copper by layer. Here losses are small and with an increase of frequency have the falling/incident character. This is caused by screening effect of copper layer. In the second group are located the screens with electrically heterogeneous copper layer. In this case the field of interferences penetrates through the slots of copper layer in steel, and losses are determined by the parameters of steel layer. In the second case of loss, it is more than in the first, almost 8-10 times (in frequency 150 kHz).

Comparing losses during the different constructions of steel layer, it is possible to note that the greatest losses introduce the layer, superimposed with the overlap of steel strips. An increase in the number of layers of screen to 3-4 or more in practice very little affects the

magnitude of losses, introduced by screen.

On the basis of the aforesaid higher it is possible to formulate following recommendations regarding the construction of the separating screens of spiral construction.

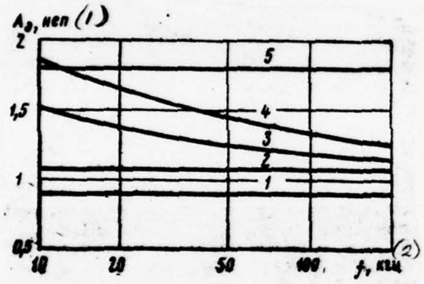

Fig. 4.14.

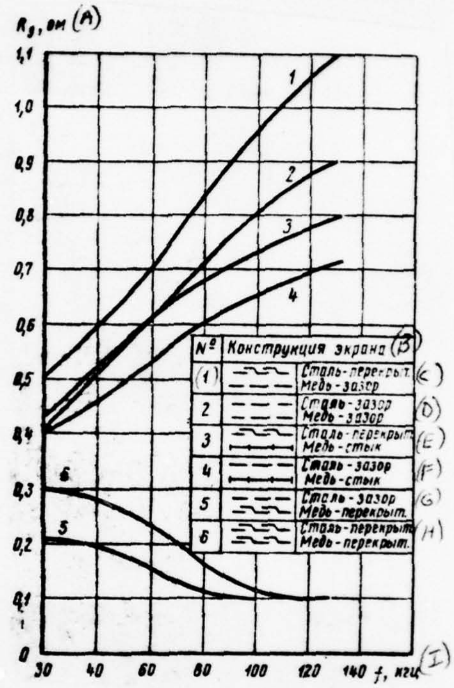

Fig. 4.15.

Fig. 4.14. screening effect of the semi-conducting screen under the varied conditions of the grounding: 1 - screen is not grounded; 2 - the grounding through 6 m; 3 - the grounding through 3 m; 4 - the grounding through 1.5 m; 5 - copper strip (40o/o coating).

Key: (1). Np. (2). kHz.

Fig. 4.15. Measurement of losses in the different

constructions of two-layered tape/strip screens.

Key: (A). ohm. (B). Construction of screen. (C). Steel is overlapped. copper - gap. (D). Steel - gap is copper - gap. (E). Steel is overlapped. copper - joint. (F). Steel - gap is copper - joint. (G). Steel - gap is copper - joint. (H). Steel it is overlapped. copper - it is overlapped. (I). kHz.

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1. Selection of materials, their combination and location must be such, so that skins of screen would give best results on attenuation of reflection A_o. and internalization - maximum values of attenuation of absorption A_n. Therefore for skins one should utilize nonmagnetic materials with large reflectivity (copper, aluminum), and for interior layers - magnetic materials (steel, Permalloy). Best of all for interior layers to use several different materials with large μ.

2. Optimum relationship/ratio of thickness of the layer depends on frequency range for which is constructed screen.

Best screening effect they give: to 10 kHz - the equal layers of copper (aluminum) stopped, from 10-20 kHz are above - the thin layers of copper (aluminum) and the thick layers of steel. The higher the frequency, the more effective the thicker layers of steel. With direct current and at very low frequencies (0-0.5 kHz), and also in the frequency region more than 1000 kHz best screening effect give uniform magnetic screens made of steel.

3. Losses, introduced by screen into circuit of transmission, determine need for having nonmagnetic skins for any frequencies. The thickness of these layers must be such so that the field of interferences would be closed in nonmagnetic metal and would not penetrate steel. For obtaining minimum losses the thickness of external (copper, alumimum) layers one should accept the equal or larger equivalent depth of penetration of the field of the highest transmitted frequency ($t \geqslant \theta$). These layers one should fulfill with overlap.

4. Layers it is to fulfill as far as possible continuous with greatest electrical uniformity. Joints and gashes in electromagnetic screens must be arrange/located so that they would have the direction along the probable path

of the propagation of eddy currents in screen and would not intersect these currents. In magnetostatic screens from magnetic material joints and gashes one should orient of the in parallel to the lines of force magnetic field of the source of interferences. Furthermore, gashes and the slots of one layer compulsorily must overlap with the continuous metallic mass of another layer.

5. Screen strips one should superimpose with space, equal to pitch of strand of circuit $(h_э=h_п)$, and in that direction, that also spiral joining. Strips must be superimposed with the overlap 2-3 mm and have the maximum width which according to design considerations it makes it possible to use the taken space of helicity $(h_э)$ and diameter of the shielded splice $(d_э)$. With technological difficulties in the imposition of screen strips with overlap (steel) is possible the imposition of two strips with gap, moreover upper strip must overlap the gap of lower.

6. Surface of screen strips must be free from oxides, corrosion and other defects so that between strips would be good electrical contact. This especially is substantial with the uncoordinated space of screen strips and pitch of chain $(h_э \neq h_п)$. Is expedient the coating of screen strips with

anticorrosive metallic composition with good electrical conductivity (tinplating and so forth).

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7. In multilayer screens screen strips must be superimposed with matched pitch of strand $(h_э=h_ц)$ so that each layer would have direction, coinciding with direction of spiral joining of turned to it lays. Screen strips must be superimposed with overlap and have maximum possible width, on the basis of the diameter of the shielded splice and taken pitch of strand.

8. For decrease in effect in communication cables shielding shells it is to ground from both end/leads of cable, the more frequent the grounding, the better.

4.4. Braiding screens.

The screens of the flexible feeder cables of antenna, assembling and station-type designation/purpose are fulfilled predominantly in the form of metallic cover/braids from

fine/thin circular wires or strips. Such screens are the complex system of the wires of round or rectangular (tape/strip) section. Cover/braid is fulfilled into two layers, one of which has right direction of lay, and another - left. Are known also the one-sided cover/braids, which have metallic strands only in one direction. Circular wires have a diameter 0.1-0.5 mm and are banked in ply of 2-4 and more wires.

In cable technology greatest propagation have the entanglements, with which each ply cover/ccats with itself two others, and, in turn, is covered by two following plys. Are most common cover/braids of 16 plys. There are cover/braids of 18-36 plys. The presence of law in the number of plys and the order of their entanglement makes it possible to establish/install the definite dependence between the diameter of screen $(d_э)$, the space of cover/braid $(h_э)$, the width of plys and a quantity of wires (or strips) in one ply.

Similar to pitch of strand, the space of cover/braid he is called the measured along the axis of cable length for extent/elongation of which a series is described the complete revolution. The most important parameter of

cover/braid is the angle, formed by the direction of ply and by the line, perpendicular to the axis of cable. To Fig. 4.16, is shown the pattern of the location of plys of one layer of cover/braid, expanded/scanned to plane.

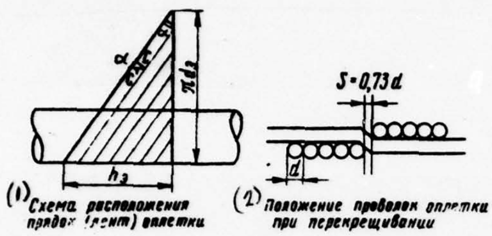

Fig. 4.16. Pattern of the location of plys of one layer of cover/braid, expanded/scanned to plane.

Key: (1). Pattern of the location of plys (strips) of braid. (2). Position of the wires of cover/braid with crossing.

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From the figure one can see that $c' = c/\cos\alpha = nd/\cos\alpha$, where c is width of ply; n - the number of wires in ply; d - the wire diameter; α - the angle of the imposition of cover/braid. Quantity of plys m (in one direction), necessary for complete coating of the surface of screen at the length of one space of cover/braid, is determined from expression $m=h_3/c'=h_3\cos\alpha/nd$.

The dependence between the space of cover/braid, the width of ply and quantity of plys is determined by formula $h_0 = mc/\cos\alpha$ or from other. Since $\mathrm{tg}\,\alpha = h_0/\pi d_0$ and cos α = of 1/ $\sqrt{1 + \mathrm{tg}^2\,\alpha}$, then

$$h_0 = \pi d_0 \frac{1}{\sqrt{\left(\frac{\pi d_0}{mc}\right)^2 - 1}}.$$

In connection with tape/strip cover/braid from flat/plane wires in these relationship/ratios, one should accept; m - the number of strips in one direction at the length of the space of cover/braid; c is width of strips.

A quantity of plys (strips) and their width is selected depending on the required density of cover/braid. The density of cover/braid is expressed as percent ratio of the surface of screen, covered with metal Π^{M}, to the complete surface of Π. For screen of one layer of cover/braid density will be determined by formula $K_1 = \frac{\Pi^{M}}{\Pi}\cdot 100 = \frac{mc}{h_0 \cos\alpha}\,100\%$ or, if it is known air-gap clearance s, K_1 = (c/c + s) 100o/o. Taking into account that cover/braid has two layers, its density will be, it is logical, another, since the clearances of one layer will partially overlap with the wires of another layer. In cable technology it is

accepted the complete density of cover/braid to calculate according to formula $K = (2K_1 - K^2_1) \cdot 100o/o$.

By cable screens the density of cover/braid, as a rule, exceeds 90o/o. In the complete absence of slots, the density of cover/braid will be 100o/o. But virtually this is inaccessible, since plys or the strips, which go in one direction, cannot lie close to each other, since them divide plys (strips), which go in the opposite direction. From Fig. 4.16, it is evident that between plys is gap with value 0.73d (where d - the diameter of the wires of cover/braid). Tape/strip cover/braid has a smaller quantity of gaps, than cover/braid from circular wires.

It is of interest to examine the following questions:

- the effect of helicity on the shielding properties;

- effect longitudinal and the transverse slots, gashes and gaps in flexible screens;

- shielding action of cover/braids with the different relationship/ratios of pitch of strand of circuit and space of the helicity of cover/braid;

- the special feature/peculiarity of the frequency dependence of screening effect of braiding screens;

- the role of contact resistance between the wires of cover/braids on screening effect such of screens;

- screening effect in the direct/straight and contrary direction of circuit and screen wires, strips;

- the density effect of cover/braid and diameter of wires (width of strips) on the shielding properties.

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The effect of helicity and the role of slots were explained on the experimental model of the screen, made from the copper strips with a width of 7-12 mm and with a thickness of 0.08 mm. Screen strips were superimposed with the different spaces of helicity $h_э=25\div100$ mm; pitch of strand of circuit $h_п=50$ mm. Between winding pitch of strips and pitch of strand of circuit, was observed strict equality $(h_э=h_п)$. The gap between strips

was retained in 2-3 mm. The results of the measurement of the screen attenuation of such slotted screens in the range of frequencies from 20 to 150 kHz are given to Figs. 4.17 and 4.18.

Examining the given results, it is possible to reveal/detect/expose the following laws:

- with an increase in pitch of strand of screen strips $(h_э=h_п)$ screen attenuation grow/rises; when $h_э=h_п=\infty$ screening effect is maximum;

- slots exert a substantial influence on screening effect, noticeably decreasing the value of screen attenuation;

- the agreement of winding pitch of screen and pitch of strand of circuit it has also great effect on the value of screen attenuation. During strict agreement of spaces $(h_э\ h_п)$ screening effect is maximum.

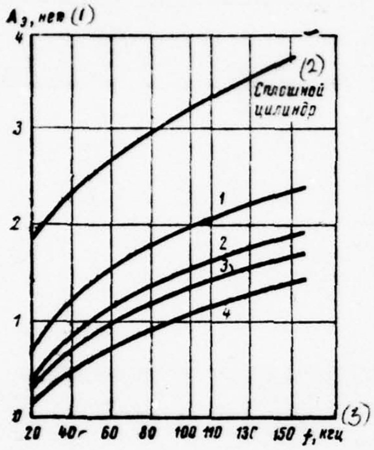

Fig. 4.17.

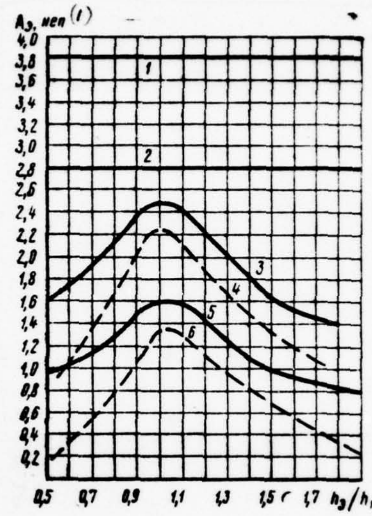

Fig. 4.18.

Fig. 4.17. Measurement of the frequency dependence of screen damping of copper cover/braid at different values $h_э/h_ц$. where 1 - $h_э/h_ц = 1$; 2 - $h_э/h_ц = 0{,}7$; 3 - $h_э/h_ц = 0{,}56$; 4 - $h_э/h_ц = 0{,}2$

Key: (1). Np. (2). Drum shell. (3). kHz.

Fig. 4.18. Screen attenuation of cover/braid from the copper strips: 1 - cylinder (f = 150 kHz); 2 - cylinder (f = 60 kHz); 3 - strip (f = 150 kHz); 4 - varnish-treated tape (f = 150 kHz); 5 - copper strip (f = 60 kHz); 6 - varnish-treated tape (f = 60 kHz).

Key: (1). Np.

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During the disagreement/mismatch of spaces, value $A_э$ decreases. So, with f = 150 kHz a change in the relationship/ratio $h_э/h_п$ from 1.0 to 0.5 is led to a decrease in the screen attenuation to 35o/o (from 2.5 to 1.9 Np). This phenomenon has completely logical physical explanation. With matched pitch of strands of circuit and winding of screen $(h_э=h_п)$ are created the most favorable conditions of the passage of eddy currents in screen (current it follows along the screen strips). With the disturbance/breakdown of equality between $h_э$ and $h_п$ eddy current, being propagated on screen with pitch of strand of circuit $(h_п)$, it encounters in its path of slot, gash, the contact resistance of wires and other obstructions, which lower eddy current and which decrease screening effect.

The effect of the agreement of pitch of strands of

circuit and helicity of screen appears both in the slotted screens and of spiral screens without slots; however, of slotted screens it manifests itself more powerfully.

To Fig. 4.19, is given the frequency dependence of the screen attenuation of screens with longitudinal and transverse gashes. Transverse gashes more adversely affect the shielding properties, than longitudinal. equipment/device of longitudinal gashes (through 8 mm) with f = 150 kHz led to a decrease in value $A_э$ from 4.8 to 3.8 Np, and equipment/device of transverse gashes (through 10 mm) led virtually to the total loss of screen properties ($A_э$=0,6 Np). The character of the frequency dependence of screens with longitudinal and transverse gashes is various. In the first case is observed an increase in screening effect with an increase of frequency approximately according to the law of continuous screen. In the second case an increase in the frequency does not give a noticeable increase in the screen attenuation.

Differently also manifests itself in screens with longitudinal and transverse slots their value. If in screens with the longitudinal slots an increase in the width of slot is led to a considerable decrease in the screen

attenuation, then in screens with the transverse slots its width plays almost no role. In screens with the longitudinal slots and gaps, the value of screen attenuation sharply changes with an increase in the width of slots. By itself presence of longitudinal gash is not produced a considerable decrease in value $A_э$.

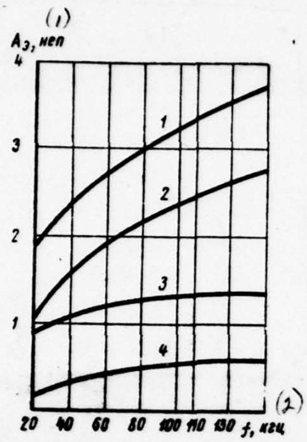

Fig. 4.19. Results of the measurement of copper screens (t = 0.08 mm) with the longitudinal (2) and transverse (3 and 4) gashes also of drum shell (1).

Key: (1). Np. (2). kHz.

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To Fig. 4.20, are given the results of the measurements of screening effect of coaxial cables in the spectrum to 5 MHz with screens from the different combinations of copper and steel cover/braids. Here for a comparison corrected values of screen damping of continuous copper tube. According to the character of frequency

dependence curves can be subdivided into two groups: purely uniform copper cover/braids (curved 1, 2, 3) and the combined cover/braids made of copper and steel (curved 4 and 5). The special feature/peculiarity of the frequency dependence of uniform copper cover/braids lies in the fact that at first they give positive effect, and then in the range of high frequencies their screening effect sharply descends. This is caused by phenomenon of the emission/radiation of high-frequency electromagnetic energy from the slots of cover/braid. The effect of slotted emission/radiation begins to manifest itself with frequency 10^5 Hz for single-layer cover/braids and 10^6 Hz for two- and three-layered cover/braids. The comparison of curves 1, 2 and 3 shows that with an increase in the number of copper cover/braids from one to three screening effect regularly it grow/rises. The second group of curves (4 and 5), which relates to that which was combined cover/braids copper - steel and copper - steel - copper, has at first rising, and then stable character in all range of frequency curve/graph to 5 MHz. Three-layered combined cover/braid (5) in terms of the absolute value of screen damping is substantially better than uniform three-layered cover/braid from copper (3), also, in the spectrum to 1 MHz virtually equivalent to the continuous copper tube with a thickness

of 0.06 mm (curve 6).

The experimental study of cable cover/braids showed that their screening effect in many respects depends on surface condition of the wire of cover/braid, value of contact resistance between wires and the quality of the imposition of cover/braid on the shielded circuits. Table 4.4 gives the results of the measurement of the contact resistance of copper and steel cover/braids. Contact resistance were establish/installed by measurement on the direct current of one meter of the cover/braid, cut on generatrix so that all wires were gashed and connection was realized only through the contact between wires. There are given measurement data of the resistor/resistance of one meter of whole cover/braid.

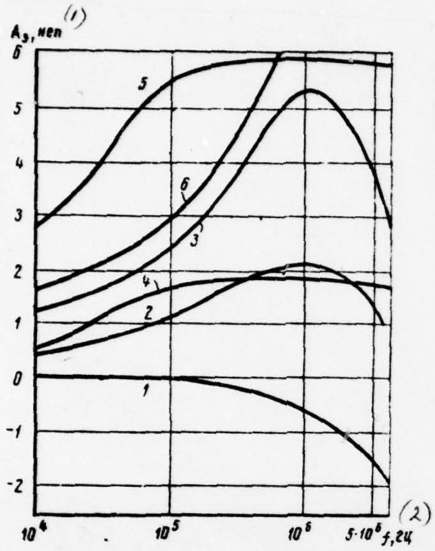

Fig. 4.20. Screening effect of metallic cover/braids in coaxial cables (results of measurements).

Key: (1). Np. (2). Hz.

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The contact resistance of steel cover/braid is incommensurable more than in copper cover/braid. If of copper contact resistance is greater than the resistor/resistance of one linear meter 7 times, then at steel virtually lacks the contact between wires. In this,

consists one of the reasons for unsatisfactory properties and instability of steel cover/braids. A screen of the type of cover/braid is unstable in time. In the course of time, the contact resistance grow/rises and screening effect descends.

Measurements establish/installed that the weakly pressed, loose cover/braid has smaller screen attenuation than dense cover/braid. Difference reaches 2 Np. Furthermore, the rewind of the cables, shielded by cover/braid, is led to a decrease in screening effect, since is disrupted make-before-break contact and deteriorates the density of cover/braid.

On the basis of the conducted investigations, it is possible to formulate following recommendations regarding the construction of flexible cable screens of the type of the cover/braid:

1) The density of cover/braid must be as large as

possible and compose 90-96o/o. An increase in the diameter of the wires of cover/braid gives certain increase in screening effect. The presence of gaps sharply decreases screening effect.

2) Tape/strip screens one should give the preference before wire, since the first possess the more favorable relationship/ratio between the overall surface of metal and gaps and have more favorable conditions for the passage of eddy currents in screen. As a result screening effect of the tape/strip screens is higher than wire ones.

3) In all cases the space of cover/braid (space of the imposition of screen strips or wires $h_э$) must be strictly agreed with spacing of the joining of circuit ($h_ш$), i.e., $h_э = h_ш$.

4) For providing the stability of the parameters of screen in time and an improvement in screening effect, is expedient to apply strips and wires with anticorrosive proofings (tinplating, silver plating, zinc plating so forth). It is necessary to approach the achievement of low contact resistance between the wires of cover/braid.

5) Copper cover/braids one should give the preference before the steel and other types of cover/braids. A deficiency/lack in the steel cover/braids is a small effect of the attenuation of reflection and the inadequacy of the contact properties of steel wires.

Table 4.4. results of the measurements of contact resistance for different cover/braids.

(1) Тип оплетки	(2) Сопротивление оплетки, ом/м	(3) Контактное сопротивление, ом/м
(4) Медь	$0,24 \cdot 10^{-2}$	$1,7 \cdot 10^{-2}$
(5) Сталь	$1,95 \cdot 10^{-2}$	$10^{[illegible]}$

Key: (1). Type of cover/braid. (2). Resistor/resistance of cover/braid, Ω/m. (3). Contact resistance, to Ω/m. (4). Copper. (5). Steel.

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6) Is very effective the application/use of the combined screen, which consists of copper and steel cover/braids. In this case the stability of shadowing is obtained in wide frequency spectrum.

7) One-way cover/braid in comparison with usual bilateral cover/braid possesses essential advantage in the expenditures of material and has somewhat best shielding characteristics because of the absence of the technological gaps, unavoidable with bilateral cover/braids. But this one-sided cover/braid can be effective only during strict agreement of spaces of cover/braid with pitch of strand of circuit and the coinciding imposition of screen strips (wires). The stability of electrical characteristics in time

of this cover/braid is worse than in usual bilateral cover/braid.

8) If necessary for the creation of the flexible screens, which have the high shielding characteristics in high-frequency range, one should apply multilayer braiding screens or utilize a cover/braid in combination with spiral screen from fine/thin copper, aluminum or steel strips.

9) In all cases of engineering flexible cable shields, it follows as far as possible to avoid gashes and the gaps, which do not coincide with direction of flow in shielded circuit, and on no account to allow/assume the disturbance of the completeness of shell in the direction, perpendicular to direction of flow in circuit. Are allow/assumed only the joints and the small gaps, which go in parallel with direction of flow in the shielded circuit. In the twisted shielded circuits the space of the helicity of slot (gap) on screen must correspond to pitch of strand of circuit.

10) is very effective the grounding of screen shell. The more frequent the grounding of screen, the greater the effect of electrostatic shadowing.

11) In the radio-frequency cables of coaxial construction the space of cover/braid must compose 45-55°, and the density of the imposition of cover/braid 90-96o/o. In this case is reached optimum screening effect, the stability of the parameters, strength and the flexibility of cable.

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Appendix

Relationship/ratio between nepers and decibels.

The attenuation of line ($a = \alpha l$) or at of four-pole is accepted to evaluate in nepers or decibels (bels). Calculation/enumerations in nepers are based on the natural system of logarithms, and in decibels (bels) - on decimal.

Attenuation in 1 Np corresponds to a decrease in the power in e^2 = 7.4 times, and current or the voltages - in e = 2.718 times:

$$a = \frac{1}{2}\ln\frac{P_0}{P_l} \quad \text{or} \quad \frac{P_0}{P_l} = e^{2a} = e^2 = 7{,}4,$$

$$a = \ln\left|\frac{U_0}{U_l}\right| = \ln\left|\frac{I_0}{I_l}\right| \quad \text{or} \quad \left|\frac{U_0}{U_l}\right| = \left|\frac{I_0}{I_l}\right| = e^a = e = 2{,}718.$$

Attenuation in 1 bel corresponds to a decrease in the power 10 times, and current or the voltages - 3.17 times:

$$a = \lg\frac{P_0}{P_l} \quad \text{or} \quad \frac{P_0}{P_l} = 10^a = 10,$$

$$a = 2\lg\left|\frac{U_0}{U_l}\right| = 2\lg\left|\frac{I_0}{I_l}\right| \quad \text{or} \quad \left|\frac{U_0}{U_l}\right| = \left|\frac{I_0}{I_l}\right| = 10^{0{,}5a} = 10^{0{,}5} = 3{,}17.$$

Decibel is one tenth part of the bel. We will respectively obtain that the attenuation in 1 dB characterizes decrease in power 1.26 times, and in current or voltage - 1.12 times:

$$a = 10\lg\frac{P_0}{P_l} \quad or \quad \frac{P_0}{P_l} = 10^{0,1a} = 10^{0,1} = 1,26,$$

$$a = 20\lg\left|\frac{U_0}{U_l}\right| = 20\lg\left|\frac{I_0}{I_l}\right| \quad or \quad \left|\frac{U_0}{U_l}\right| = \left|\frac{I_0}{I_l}\right| = 10^{0,05a} = 10^{0,05} = 1,12.$$

In Table P.1.1 corrected values of attenuation in decibels with the different relationship/ratios of power.

Between nepers and decibels there is the following relationship/ratio:

$$a_{[дб]} = 20\lg\left|\frac{U_0}{U_l}\right| = 20\lg e^{a_{[неп]}} = 20a_{[неп]}\lg e = 20a_{[неп]}\,0,4343 = 8,686a_{[неп]},$$

i.e. a [dB] = 8.686 a [Np]. Consequently, 1 Np - 8.686 dB, 1 dB - 0.115 Np.

Are given below conversion tables Np - dB and dB - Np (Tables P.1.2 and P. 1.3).

Table P.1.1.

a, дб (1)	0,1	1	2	3	4	5	6	7	8	9	10	$10 \cdot n$
$\frac{P_0}{P_l}$	1,02	1,26	1,58	1,99	2,51	3,16	3,98	5,01	8	9	10	10^n

Key: (1). dB.

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Table P.1.2. Translation/conversion of nepers into decibels.

(1) неп	(2) дб	(1) неп	(2) дб	(1) неп	(2) дб	(1) неп	(2) дб	(1) неп	(2) дб	(1) неп	(2) дб	(1) неп	(2) дб	(1) неп	(2) дб
0,01	0,087	1,4	12,2	3,7	32,1	6,0	52,1	8,3	72,1	10,5	91,2	12,7	110,3	14,9	129,4
0,02	0,174	1,5	13,0	3,8	33,0	6,1	53,0	8,4	73,0	10,6	92,1	12,8	111,8	15,0	130,3
0,03	0,261	1,6	13,9	3,9	33,9	6,2	53,9	8,5	73,8	10,7	92,9	12,9	112,0	15,1	131,2
0,04	0,347	1,7	14,8	4,0	34,8	6,3	54,7	8,6	74,7	10,8	93,8	13,0	112,9	15,2	132,0
0,05	0,434	1,8	15,6	4,1	35,6	6,4	55,6	8,7	75,6	10,9	94,7	13,1	113,8	15,3	132,9
0,06	0,521	1,9	16,5	4,2	36,5	6,5	56,5	8,8	76,4	11,0	95,6	13,2	114,7	15,4	133,8
0,07	0,608	2,0	17,4	4,3	37,3	6,6	57,3	8,9	77,3	11,1	96,4	13,3	115,5	15,5	134,6
0,08	0,695	2,1	18,2	4,4	38,2	6,7	58,2	9,0	78,2	11,2	97,3	13,4	116,4	15,6	135,5
0,09	0,782	2,2	19,1	4,5	39,1	6,8	59,1	9,1	79,0	11,3	98,1	13,5	117,3	15,7	136,4
0,1	0,869	2,3	20,0	4,6	40,0	6,9	59,9	9,2	79,9	11,4	99,0	13,6	118,2	15,8	137,2
0,2	1,74	2,4	20,8	4,7	40,8	7,0	60,8	9,3	80,8	11,5	99,9	13,7	119,0	15,9	138,1
0,3	2,61	2,5	21,7	4,8	41,7	7,1	61,7	9,4	81,6	11,6	100,8	13,8	119,9	16,0	139,0
0,4	3,47	2,6	22,6	4,9	42,6	7,2	62,5	9,5	82,5	11,7	101,6	13,9	120,8	16,1	139,8
0,5	4,34	2,7	23,5	5,0	43,4	7,3	63,4	9,6	83,4	11,8	102,5	14,0	121,7	16,2	140,7
0,6	5,21	2,8	24,3	5,1	44,3	7,4	64,3	9,7	84,3	11,9	103,4	14,1	122,5	16,3	141,6
0,7	6,08	2,9	25,2	5,2	45,2	7,5	65,1	9,8	85,1	12,0	104,2	14,2	123,3	16,4	142,4
0,8	6,95	3,0	26,1	5,3	46,0	7,6	66,0	9,9	86,0	12,1	105,1	14,3	124,2	16,5	143,3
0,9	7,82	3,1	26,9	5,4	46,9	7,7	66,9	10,0	86,9	12,2	106,0	14,4	125,1	16,6	144,2
1,0	8,69	3,2	27,8	5,5	47,8	7,8	67,8	10,1	87,7	12,3	106,8	14,5	125,9	16,7	145,1
1,1	9,55	3,3	28,7	5,6	48,6	7,9	68,6	10,2	88,6	12,4	107,7	14,6	126,8	16,8	145,9
1,2	10,4	3,4	29,5	5,7	49,5	8,0	69,5	10,3	89,5	12,5	108,6	14,7	127,7	16,9	146,8
1,3	10,4	3,5	30,4	5,8	50,4	8,1	70,4	10,4	90,3	12,6	109,4	14,8	128,6	17,0	147,7
		3,6	31,3	5,9	51,2	8,2	71,2								

Key: (1). Np. (2). dB.

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Table P.1.3. Translation/conversion of decibels into nepers.

дб (1)	неп (2)	дб (1)	неп (2)	дб (1)	неп (2)	дб (1)	неп (2)	дб (1)	неп (2)	дб (1)	неп (2)	дб (1)	неп (2)	дб (1)	неп (2)
0,1	0,0115	14	1,61	37	4,26	60	6,91	83	9,55	105	12,1	127	14,6	149	17,2
0,2	0,0230	15	1,73	38	4,37	61	7,02	84	9,67	106	12,2	128	14,7	150	17,3
0,3	0,0345	16	1,84	39	4,49	62	7,14	85	9,79	107	12,3	129	14,9	151	17,4
0,4	0,0461	17	1,96	40	4,61	63	7,25	86	9,90	108	12,4	130	15,0	152	17,5
0,5	0,0576	18	2,07	41	4,72	64	7,37	87	10,0	109	12,5	131	15,1	153	17,6
0,6	0,0691	19	2,19	42	4,84	65	7,48	88	10,1	110	12,7	132	15,2	154	17,7
0,7	0,0806	20	2,30	43	4,95	66	7,60	89	10,2	111	12,8	133	15,3	155	17,8
0,8	0,0921	21	2,42	44	5,06	67	7,71	90	10,4	112	12,9	134	15,4	156	18,0
0,9	0,1036	22	2,53	45	5,18	68	7,83	91	10,5	113	13,0	135	15,5	157	18,1
1	0,115	23	2,65	46	3,30	69	7,94	92	10,6	114	13,1	136	15,7	158	18,2
2	0,230	24	2,76	47	5,41	70	8,06	93	10,7	115	13,2	137	15,8	159	18,3
3	0,345	25	2,88	48	5,52	71	8,17	94	10,8	116	13,4	138	15,9	160	18,4
4	0,461	26	2,99	49	5,64	72	8,29	95	10,9	117	13,5	139	16,0	161	18,5
5	0,576	27	3,11	50	5,76	73	8,40	96	11,0	118	13,6	140	16,1	162	18,6
6	0,691	28	3,22	51	5,87	74	8,52	97	11,2	119	13,7	141	16,2	163	18,8
7	0,806	29	3,34	52	5,99	75	8,63	98	11,3	120	13,8	142	16,3	164	18,9
8	0,921	30	3,45	53	6,10	76	8,75	99	11,4	121	13,9	143	16,5	165	19,0
9	1,04	31	3,57	54	6,22	77	8,87	100	11,5	122	14,0	144	16,6	166	19,1
10	1,15	32	3,68	55	6,33	78	8,98	101	11,6	123	14,2	145	16,7	167	19,2
11	1,27	33	3,80	56	6,45	79	9,09	102	11,7	124	14,3	146	16,8	168	19,3
12	1,38	34	3,91	57	6,56	80	9,21	103	11,9	125	14,4	147	16,9	169	19,5
13	1,50	35	4,03	58	6,68	81	9,32	104	12,0	126	14,5	148	17,0	170	19,6
		36	41,4	59	6,79	82	9,44								

Key: (1). dB. (2). Np.

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